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A METHODOLOGY FOR BOOST-GLIDE TRANSPORT TECHNOLOGY PLANNING

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16. Abstract

This document provides a systematic procedure by which the relative economic value of technology factors affecting design, configuration, and operation of boost-glide transport can be evaluated. Use of the methodology results in identification of first-order economic gains potentially achievable by projected advances in each of the definable, hypersonic technologies. Starting with a baseline vehicle, the formulas, procedures and forms which are integral parts of this methodology are developed. A demonstration of the methodology is presented for one specific boost-glide system.

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FOREWORD

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SYMBOLS

a_g	acceleration of gravity, m/sec^2 (ft/sec^2)
A_{TPS}	area protected by TPS, m^2 (ft^2)
BGT	boost-glide transport
C_{AF}	cost of BGT airplane less engines and avionics, \$
C_{AV}	cost of avionics equipment per aircraft, \$
C_{BGT}	cost of BGT airplane (total), \$
C_D	hypersonic drag coefficient (drag/qS)
$C_{D_i}/C_L{}^2$	hypersonic induced drag factor
C_{D_o}	hypersonic zero-lift drag coefficient
C_H	cost of hydrogen per unit weight, \$/kg (\$/lb)
C_L	hypersonic lift coefficient (lift/qS)
C_{ME}	cost of rocket engine set per aircraft, \$
C_O	cost of oxygen per unit weight, \$/kg (\$/lb)
C_{TJ}	cost of turbojet engine set per aircraft, \$
DOC	direct operating cost, \$ per ton statute mile (or ¢ per ton statute mile)
E	modulus of elasticity, N/m^2 $(lb/in.^2)$
f_{cy}	compressive yield stress, N/m^2 $(lb/in.^2)$
f_{ty}	fuselage material properties parameter

F_E	design factor for empennage weight
$F_{F,B}$	design factor for fuselage structure designed by buckling criteria
$F_{F,C}$	design factor for fuselage structure designed by crippling criteria
$F_{F,F}$	design factor for fuselage structure not designed by primary loads
$F_{F,S}$	design factor for fuselage structure designed by stiffness criteria
$F_{F,Y}$	design factor for fuselage structure designed by yield criteria
F_P	design factor for propellant system weight
$F_{W,B}$	design factor for wing structure designed by buckling criteria
$F_{W,C}$	design factor for wing structure designed by crippling criteria
$F_{W,F}$	design factor for wing structure not designed by primary loads
$F_{W,S}$	design factor for wing structure designed by stiffness criteria
$F_{W,Y}$	design factor for wing structure designed by yield criteria
FMP	fuselage material properties parameter
GLOW	gross lift-off weight, kg (lb)
IR	annual insurance rate, %/100
I_{SP}	specific impulse, $\frac{\text{N-sec}}{\text{kg}}$ $\left(\frac{\text{lb}_f\text{-sec}}{\text{lb}_m}\right)$
K_R	reserve fuel fraction (ratio of reserve to main fuel)

K_{TPS}	fraction of original TPS manufacturing cost required per flight for TPS maintenance
L_d	depreciation life of aircraft, years
L/D	cruise lift-drag ratio
LF	average load factor (ratio of average payload carried to normal maximum capability), %/100
L_{TPS}	useful life of thermal protection system (flights)
MR	mixture ratio (O_2/H_2)
N_{ME}	number of rocket engines per aircraft
N_{TJ}	number of turbojet engines per aircraft
q	free stream dynamic pressure, N/m^2 (lb/ft^2)
R_A	range covered during ascent, km (statute miles)
R_c	cruise range, km (statute miles)
R_{D+L}	range during descent and landing, km (statute miles)
R_G	glide range, km (statute miles)
r_L	average maintenance labor rate, all personnel, \$/manhour
RSI	reusable surface insulation
R_T	operational range, km (statute miles)
S	reference area, m^2 (ft^2)
t_B	block time, hr
t_F	time of flight, hr
T_{ME}	main engine thrust, N (lb)

T_{TJ}	turbojet thrust (sea-level static) per engine, N (lb)
$(T/W)_{GLOW}$	maximum thrust to weight ratio at take-off, N/kg
U	aircraft utilization, block hr/yr
V_B	block velocity (operational range/elapsed time), km/hr (MPH)
V_{BO}	vehicle burnout velocity
V'_{BO}	vehicle burnout velocity with empirically adjusted effect of earth's rotation
V''_{BO}	vehicle burnout velocity including term contributed by the earth's rotation
$V_{R_\oplus}$	rotational velocity of the earth at the equator, m/sec (ft/sec)
W_{AF}	weight of BGT aircraft excluding main propellants, propulsion, avionics, payload, and wet airframe items, $\left(W_{GLOW} - W_{P_T} - W_{TJ} - W_{ME} - W_{PL} - W_{Misc}\right)$, kg (lb)
W_{AV}	weight of avionics equipment per aircraft, kg (lb)
W_{BO}	weight at end boost, kg (lb)
W_e	empty weight $\left(W_e = W_{GLOW} - W_{P_T} - W_{Misc} - W_{PL}\right)$, kg (lb)
W_{P_D}	propellants consumed during descent, kg (lb)
W_{P_R}	reserve propellants, kg (lb)
W_{P_T}	weight of main propellants, kg (lb)
W'_F	total fuselage structural weight minus the fuselage fixed weight $\left(W_F - W_{F,F}\right)$, kg (lb)
$W_{F,F}$	fuselage fixed structural weight (weight of all fuselage elements not designed by primary loads), kg (lb)

W_{ME}	installed weight of main engines per aircraft, kg (lb)
W_{Misc}	weight of crew, residuals, power reserve and in-flight losses, kg (lb)
WMP	wing material properties parameter
W_{PL}	weight of normal maximum payload, kg (lb)
$(W/S)_{BO}$	reference wing loading at burn-out, kg/m^2 (lb/ft^2)
W_{TPS}	thermal protection system weight, kg (lb)
$(W/T)_{ME}$	main engine weight to thrust, kg/N
$(W/T)_{TJ}$	turbojet propulsion specific weight $\left(\frac{W_{TJ}/N_{TJ}}{T_{TJ}}\right)$, kg/N
W_{TJ}	installed weight of turbojet engines and ducts per aircraft, kg (lb)
W'_W	total wing weight minus the wing fixed weight $\left(W_W - W_{W,F}\right)$, kg (lb)
$W_{W,F}$	wing fixed weight (weight of all wing elements not designed by primary loads), kg (lb)
ρ	material density, kg/m^3 (lb/ft^3)
ϕ	launch azimuth (North = 0°, East = 90°, . . .)
θ	lattitude of launch

DEFINITIONS

Driver	A parameter in the DOC formula which significantly impacts DOC and which is directly relatable to hypersonic technology
Technology Parameter	A parameter which relates Drivers to specific areas of hypersonic research

INTRODUCTION AND SUMMARY

The objective of this study is to provide a systematic procedure for evaluating the relative value of technology factors affecting design, configuration, and operation of a boost-glide transport (BGT). Emphasis is on the potential economic gains achievable through projected advances in hypersonic technologies.

In this context, the "systematic procedure" is a "tool" intended for NASA's use - by which the potential payoff from alternative hypersonic research objectives may be quantitatively evaluated. As such, this "tool" is intended to complement the existing practices and procedures which NASA uses in its technology planning process.

The logic of the subject method, developed in reference 1, is illustrated in figure 1. The method begins with the definition of a baseline BGT. The baseline may be any configuration for which it is desired to determine the relative values of potential technology improvements in support of technology planning. The present method calls for the baseline to be obtained from an independent study or to be synthesized from independent data sources. The output of this first step is vehicle and mission data which are specifically required to initiate the succeeding steps.

The second step in the method is to use formulas for the computation of Direct Operating Costs (DOC) for the baseline. These formulas comply with Air Transport Association of America conventions, but are modified to reflect projected boost-glide factors. This step also identifies the DOC "Drivers"; i.e., parameters of the DOC formulas which are directly relatable to hypersonic technology and which have significant impact on the DOC.

The third step in the method is to compute the impact upon the DOC Drivers of variations in Technology Parameters (TP's). By definition, TP's are parameters which are lower-tier to the Drivers and which are relatable to specific areas of hypersonic research. The baseline TP's will have been specified within the data obtained from the first step.

The fourth step involves projections of technology advances beyond the state-of-the-art incorporated in the baseline BGT. The projections are made at the level of the Technology Parameters referenced above. These projections, made by the appropriate technology specialists, are prime inputs to the following step.

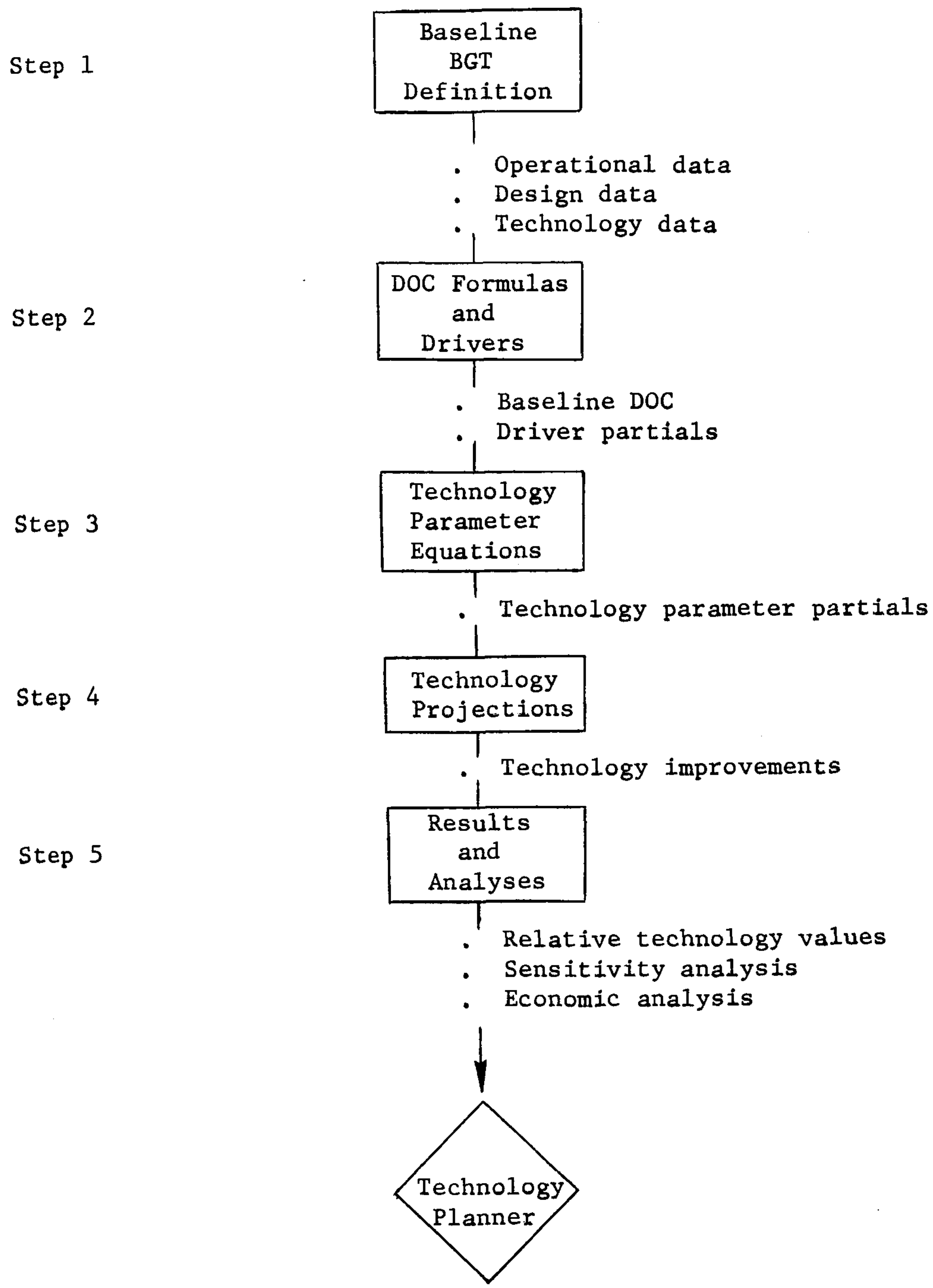


Figure 1.- Method Logic

The fifth step integrates the preceding data to produce estimates of the potential DOC savings afforded by advances in the hypersonic technologies. The relative DOC savings per technology area is the major product of the subject method. To qualify the product, step five includes sensitivity and economics analyses. The sensitivity analysis examines the impact of uncertainties upon the relative economic values of the technologies. The uncertainties apply to the semiempirical constants contained in the DOC formulas and to the projected technology improvements. If the sensitivity and economic analyses qualify the results to be valid and meaningful, the product is appropriately packaged to be transmitted to the person(s) or organization(s) who are responsible for technology planning.

Scope and Qualifications

The subject method has been designed to provide a quantitative rationale which will support NASA's planning and resource allocation for boost-glide vehicle technology. The depth of analysis and the accuracy requirements imposed on the method are appropriate to this objective. The final step in the method is particularly designed to eliminate spurious information.

In general, the method applies to any passenger or cargo-carrying boost-glide mission where the aircraft is of the vertical take-off, horizontal landing type, and utilizes rocket engines for propulsion.

The user of the method is cautioned, however, to limit its application to its intended objective: to support technology planning. The results of the method are not intended to evaluate the economics of boost-glide operations, nor to evaluate aircraft design or operational features. For such purposes, independent studies would be performed.

Organization of Report

The method is modularized to permit ease of communication and data handling between the various personnel who would participate in its application. In total, there are six method modules - five corresponding to the five steps discussed earlier and a sixth which provides project direction and integration for the total activity. These six method modules are listed, as follows, by title:

MM No. 1 - Method Integration

MM No. 2 - Baseline BGT Definition

MM No. 3 - DOC Formulas and Drivers

MM No. 4 - Technology Parameter Equations

MM No. 5 - Technology Projections

MM No. 6 - Results and Analyses

Each method module is essentially a set of instructions and procedures to be applied by the user in developing the output required of his particular module. Each module contains detailed instructions and procedures, a statement of the input data required, the output data to be produced, and an example demonstration of the method.

Demonstration

The methodology and procedures were applied to an example case during the study to illustrate their use. The full presentation of the demonstration appears in five parts, one demonstration section in each of modules 2 - 6, inclusively. This section is a brief summary of the demonstration.

Baseline BGT (Module 2).- The general arrangement of the baseline BGT is shown in figure 2. The vehicle employs a flat-bottomed body having a constant cross-sectional shape developed by NASA/LRC. Its double-delta wing planform is based on Space Shuttle orbiter phase C findings. In addition, a canard control surface is deployed for control and lift augmentation for subsonic flight only.

Liquid hydrogen is carried in a hybrid integral tank having three cells for packaging efficiency. A multi-cell liquid oxygen tank is integral with the wing carry-through. The payload compartment is also integrated with the carry-through/tank structure. Figure 2 shows the payload compartment for a passenger version having a 195 passenger-seat allocation.

The main propulsion system employs twelve engines derived from the Shuttle orbiter main engines. Thrust-weight ratio at lift-off for the vertical launch is 1.25. The engines are throttled and shut-down sequentially to limit boost acceleration to 2 g.

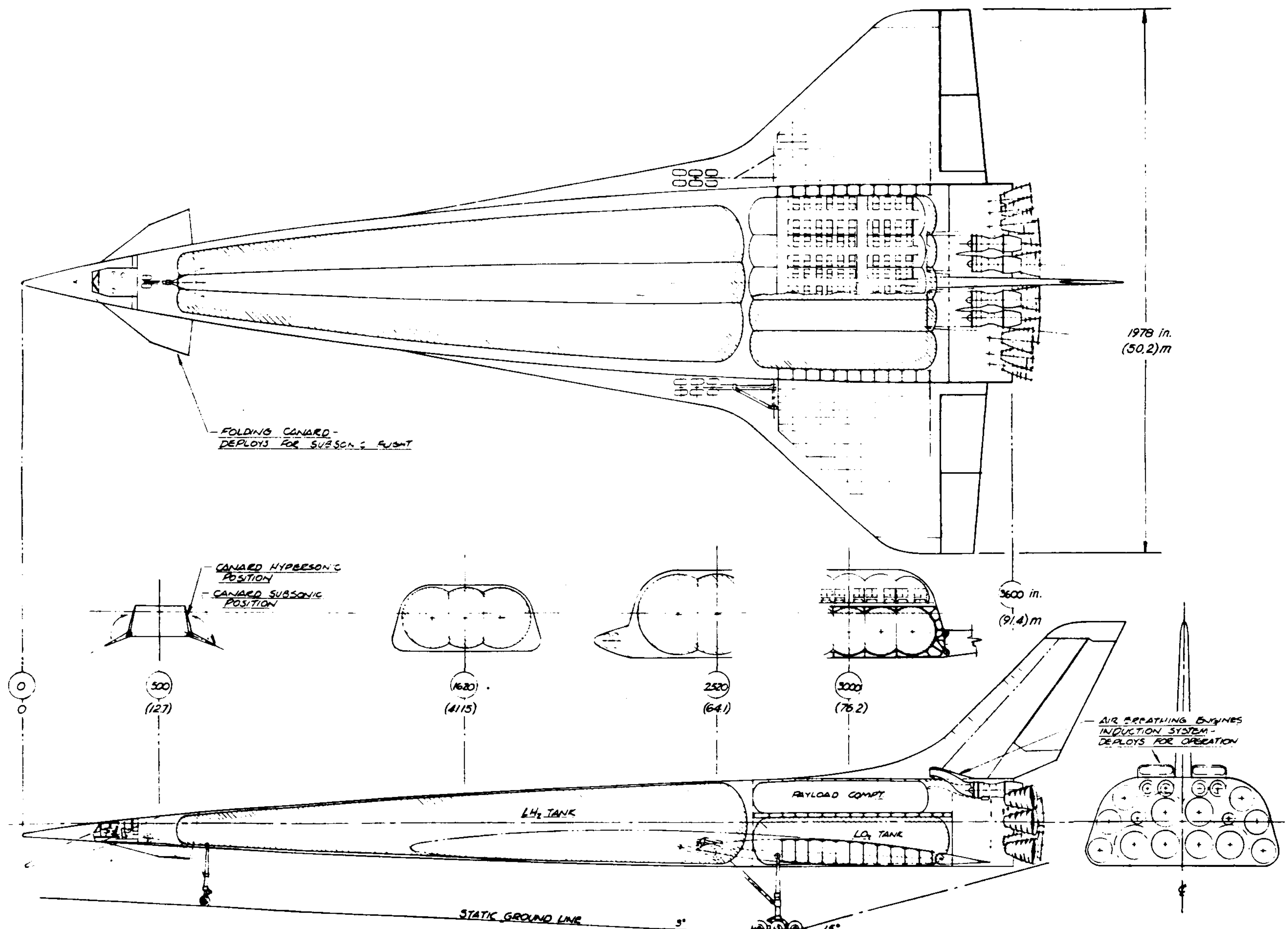


Figure 2.- Baseline Boost-Glide Transport

Four hydrogen-burning turbojets are employed for loiter, descent and horizontal landing. The engines are scaled from a hydrogen-burning version of the F401-PW-400 engine as studied by Pratt and Whitney for Shuttle application. A horizontal take-off optional capability for ferry missions is available with four "bolt-on" nacelle-type modules using the same engine.

The basic aluminum alloy airframe is protected by a fully reusable thermal protection system (TPS) replaceable after 500 flights. The TPS, which is based on the Shuttle orbiter, consists of ceramic and elastomeric reusable surface insulation and reinforced carbon-carbon in the wing leading edge and nose cap.

The technology state-of-the-art for the baseline BGT in this demonstration is advanced post-Shuttle technology with the additional qualification that the technology represent a natural follow-on to Shuttle.

Summary weight and performance characteristics of the baseline BGT are:

Gross take-off weight	1 814 000 kg (4 000 000 lb)
Landing weight	277 600 kg (612 000 lb)
Dry weight	243 600 kg (537 000 lb)
Payload weight	19 050 kg (42 000 lb)
Total range (due-East launch)	17 190 km (10 680 s. mi.)
Hypersonic lift-drag ratio	3.0
Main engine specific impulse (vac)	4560 N-sec/kg (465 lb_f-sec/lb_m)

Summary operational characteristics are :

Operational time period: post-2000
Operational load factor of 60 per cent
Block time of 1.5 hours
Airframe depreciable life of 10 years
7143 flight cycles during depreciable life

DOC Formulas and Drivers (Module 3). - The baseline Direct Operating Costs (DOC) computed for this baseline BGT, using the equations developed in the study, are shown in Table I. These values are used as the base values from which the effects of technology improvements are computed.

TABLE I.- BASELINE DIRECT OPERATING COSTS

DOC Element	DOC - ¢/ton-mile
Propellant	59.0
Depreciation	23.4
Maintenance	95.1
Insurance	5.6
Crew	0.8
Total	183.9 ¢/ton-mile

The total DOC of about 184 ¢/ton-mile for the baseline BGT corresponds to 12.3 ¢/seat-mile for a passenger version of the transport. Comparative DOC values projected for a 747-class subsonic transport in the same time period are 12.6 ¢/ton-mile and 0.84 ¢/seat-mile. The substantial difference underscores the need for cost-reducing technology advancements from the state-of-the-art assumed for the baseline in this demonstration.

Driver partials, as indicated for step 2 in figure 1, are an important output of Module 3. These partials are defined as (ΔDOC/DOC) divided by (ΔDriver/Driver). They are presented graphically in figure 3 as "% change in DOC" versus "% change in Driver." The linearity of the relationships is an approximation for use in this method. The negative slopes for the L/D and I_{SP} partials show that an increase in these parameters reduces DOC. Conversely, the positive slopes for (W_{AF}/GLOW), $(W/T)_{ME}$ and $(W/A)_{TPS}$ indicate that reductions in the values of these parameters reduce DOC. The steeper slopes represent higher percentage sensitivities of DOC to Driver improvements.

<u>Technology Parameter Equations (Module 4)</u>.- Technology Parameters are shown in Table II in relation to the six DOC Driver parameters. The design factor parameters (listed under W_{AF}/GLOW) are subdivided in Module 4 to apply specifically to structure designed by buckling, crippling, stiffness or yield criteria and by primary loads. Note that four of the Driver parameters, I_{SP}, $(W/A)_{TPS}$, L_{TPS} and (W_{ME}/T), serve a second function as their own Technology Parameters. The Technology Parameter partials, i.e., - (ΔDriver/Driver)/ (ΔTechnology Parameter/Technology Parameter) are the primary output of Module 4. These partials appear in Table 4-VII of this report, and are not repeated here.

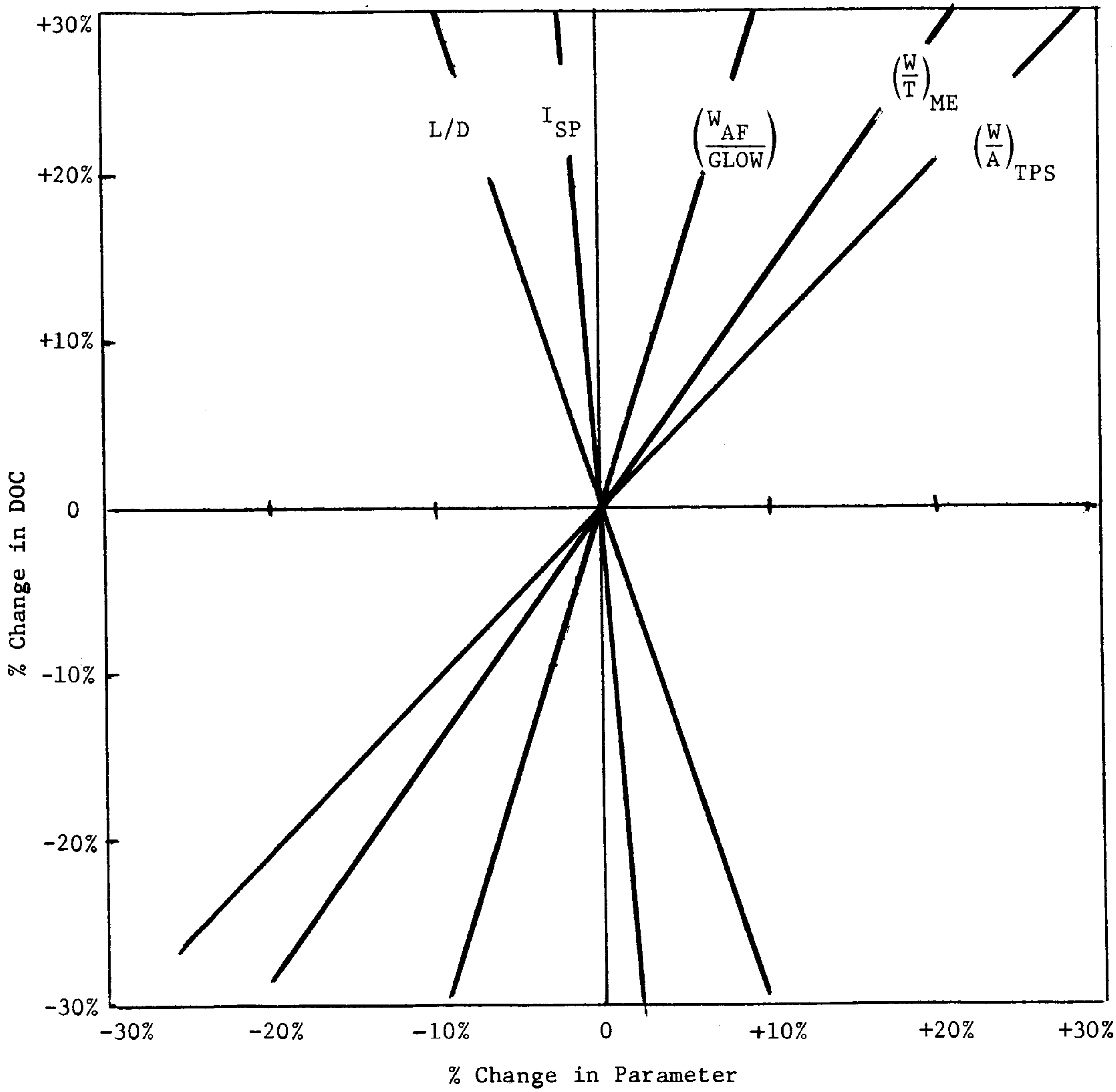


Figure 3.- Driver Parameter Sensitivities

TABLE II.- DRIVER PARAMETERS AND TECHNOLOGY PARAMETERS

	DRIVER PARAMETERS					
	$W_{AF}/GLOW$ Airframe Weight Fraction	L/D Lift-to-Drag Ratio	I_{SP} Specific Impulse	$\left(\frac{W}{A}\right)_{TPS}$ Thermal Protection System Unit Weight	L_{TPS} Thermal Protection System Life	$\left(\frac{W_{ME}}{T}\right)$ Main Engine Weight to Thrust
TECHNOLOGY PARAMETERS	F_{MP} - fuselage material parameter (-10%)	C_{D_o} - zero lift drag coeff. (-10%)	I_{SP} (0%)	$\left(\frac{W}{A}\right)_{TPS}$ (-10%)	L_{TPS} (+1328%)	$\left(\frac{W_{ME}}{T}\right)$ (-10%)
	W_{MP} - wing material parameter (-10%)	C_{D_i}/C_L^2 - induced drag factor (-2.5%)				
	F_W - wing design factor (+10%)					
	F_F - fuselage design factor (+10%)					
	F_i - other element design factors (+10%)					

Technology Projections (Module 5).- During the study, potential improvements in the Technology Parameters were projected by Rockwell specialists. This is step 4 in figure 1. These projected improvements are summarized in Table II, appearing as percentage values in parentheses. The full summary of the technology projection in this demonstration is presented in Table 5-V of this report.

Results and Analysis (Module 6).- Potential reductions in DOC for projected improvements in the individual technology parameters were obtained by multiplying:

Driver partials from Module 3 x
individual Technology Parameter partials from Module 4 x
technology projections (conservative, nominal and
    optimistic) from Module 5 x
baseline DOC of 183.9 ¢/ton-mile from Module 3

Where "conservative" and "optimistic" projections were not available, they were assumed to be 0.6 and 1.4 times the "nominal" projections. The results from the calculation for the "nominal" projection only are summarized in the first numerical column in Table III. These values may be compared to indicate relative effectiveness of projected improvements in individual technologies in reducing DOC, but may not be combined or totaled.

The last three columns in Table III show the potential contribution of each technology parameter and each Driver to the reduction in the DOC of the baseline BGT resulting from the projected improvements in all the Technology Parameters taken together. The total potential reductions in DOC for the three projections are subtracted from the baseline value in the following tabulation to yield potential DOC's:

Projection	Baseline DOC ¢/ton-mile	ΔDOC ¢/ton-mile	Potential DOC ¢/ton-mile
Conservative	183.9	- 83.5	100.4
Nominal	183.9	-129.4	54.5
Optimistic	183.9	-163.2	20.7

The "nominal" technology projection, as an example, is seen to reduce DOC by over 70 per cent.

TABLE III.- SUMMARY OF RELATIVE DOC REDUCTION VALUES OF TECHNOLOGY FACTORS

Driver and Technology Parameter	Indiv. reduction in DOC, ¢/ton-mi, by change in Technology Parameter 50% confid.	Combined effect of technology factors in reducing DOC, ¢/ton-mile		
		Conservative projection 90% confid.	Nominal projection 50% confid.	Optimistic projection 10% confid.
L/D	- -	(0)	(18.0)	(26.2)
C_{D_o}	19.7	0	12.1	17.6
C_{D_i}/C_L^2	9.6	0	5.9	8.6
I_{SP}	- -	(0)	(0)	(30.0)
I_{SP}	0	0	0	30.0
$(W/T)_{ME}$	- -	(12.3)	(15.6)	(15.9)
$(W/T)_{ME}$	25.4	12.3	15.6	15.9
$(W_{AF}/GLOW)$	- -	(48.7)	(62.0)	(63.1)
Fuselage material properties, FMP	27.0	13.1	16.6	16.9
Wing material properties, WMP	9.0	4.3	5.5	5.6
Fuselage design factors, $\sum F_F$	26.9	13.0	16.6	16.9
Wing design factors, $\sum F_W$	8.9	4.3	5.5	5.6
Propellant syst. design factor, F_{PS}	26.3	12.7	16.2	16.5
Empennage design factor, F_E	2.6	1.3	1.6	1.6
$(W/A)_{TPS}$	- -	(9.8)	(12.6)	(12.7)
$(W/A)_{TPS}$	20.4	9.8	12.6	12.7
L_{TPS}	- -	(12.7)	(21.2)	(15.3)
L_{TPS}	34.2	12.7	21.2	15.3
Total reduction in DOC by combined technology factors		83.5	129.4	163.2

Adding an indirect operating cost, estimated at 10¢ per ton-mile for the BGT, yields estimated total operating costs, TOC, of:

Projection	Estimated TOC, ¢/ton-mile
Conservative	110.4
Nominal	64.5
Optimistic	30.7

Figure 4 presents in graphical format the combined effects data from the "nominal" projection of Table III. Additionally, it relates the potential DOC reductions to the percent improvement in the Drivers.

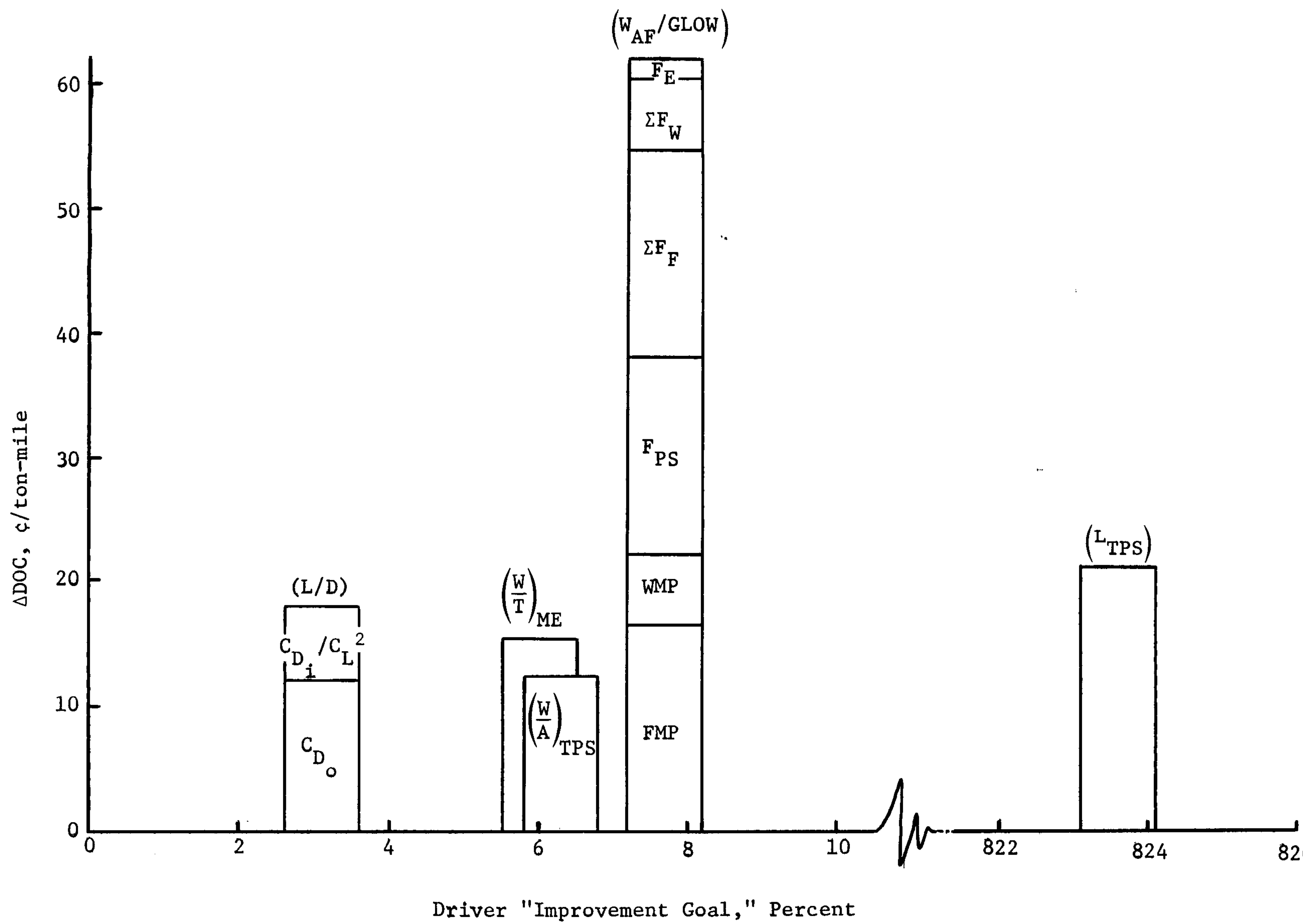


Figure 4.- Results Summary Chart

REFERENCE

1. Repic, E. M., Olson, G. A., and Milliken, R. J.: "A Methodology for Hypersonic Transport Technology Planning," NASA CR 2286, June 1973.

METHOD MODULE 1

METHOD INTEGRATION

METHOD MODULE 1 - METHOD INTEGRATION

Logic

The subsequent modules of this six-module set present data, equations, and procedures to establish the relative economic value of technology factors as an aid in planning future technology programs for a boost-glide transport (BGT). This module provides the procedures, instructions, and explanatory material required to initiate, monitor, and integrate the work defined in the other five modules.

In all that follows, it is assumed that the user of the overall methodology, generally the technology planner, will have available to him the services of appropriate technologists and system specialists, as required. The user, hereafter called the Project Office, is expected to act as coordinator, and it is recommended (although not required) that he also personally perform the calculations described in Module 6 to establish the relative technology values for the baseline vehicle being considered. This recommendation is made based on exploratory use of the methodology by the authors in which it was found that personal participation in the final calculations was of great help in fully understanding the results.

The interaction of the Project Office and the five modules comprising the basic methodology is shown in figure 1-1. A basic function of the Project Office is to monitor the outputs of the modules and assure the availability of required input data to each module. This means that all module outputs should be reviewed by the Project Office prior to being distributed to other participants. If the material is incomplete or questionable, the Project Office must supplement or change the data prior to passing it on. In order to accomplish these tasks efficiently, the Project Office should develop, publish, and maintain a schedule of these tasks to assure coordination between modules and participants. Specific instructions and recommendations for achieving the above goals are presented in this module.

Conditions and Qualifications

Consistent with the overall methodology and practices, the BGT baseline definition method applies specifically to boost-glide vehicles utilizing rocket engines and employing vertical take-off and horizontal landing.

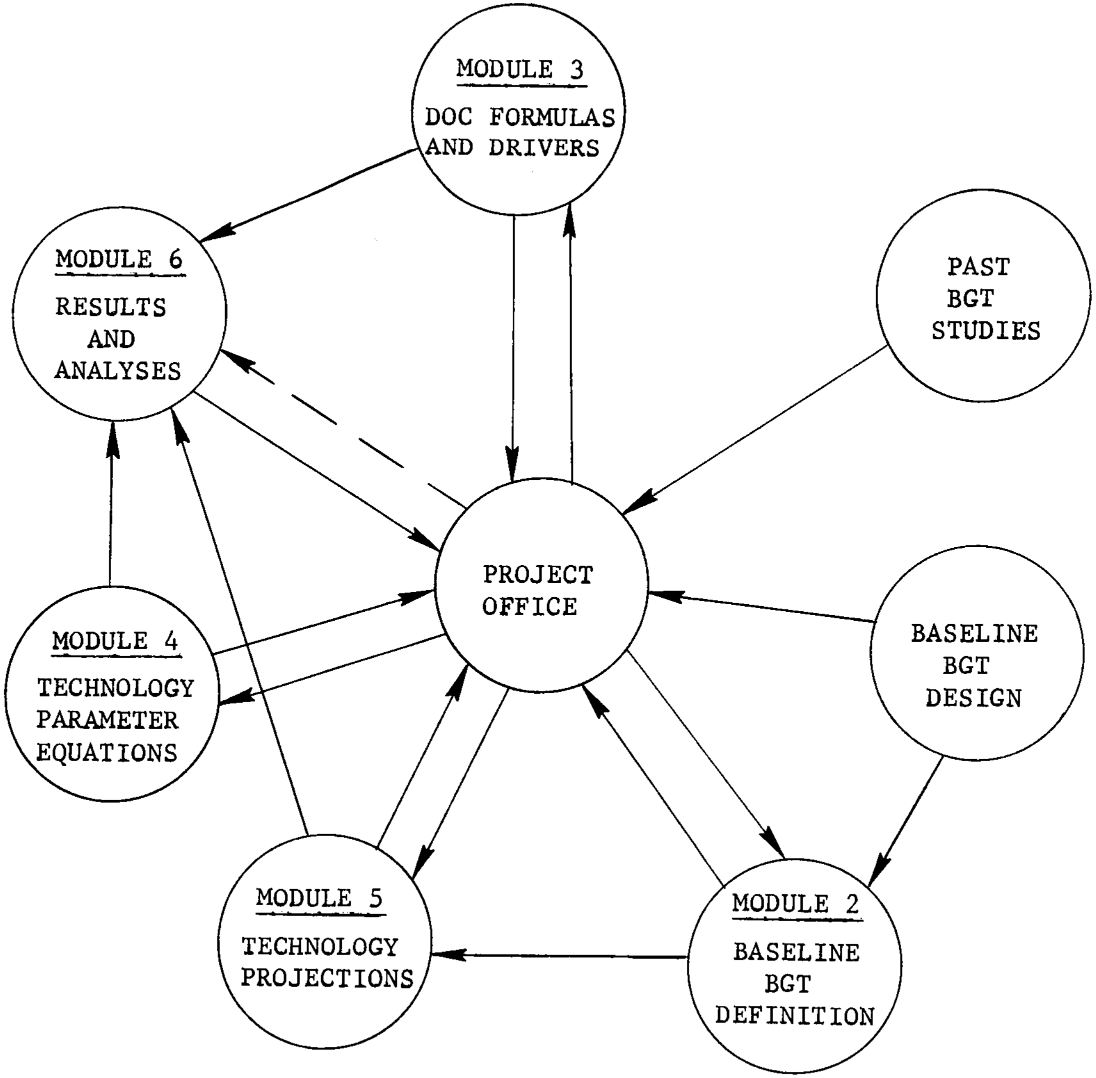


Figure 1-1.- Method Integration Logic

Conditions must be observed concerning the technology of the BGT. First, the baseline must be predicated on the technology level of a specific base time period. Next, the technology advances must be postulated beyond the base period to yield an improved technology level by a specific target time period. Then the methodology presented herein will properly show the relative values of technology improvements between the base and target time periods.

Input Data

Effective use of the methodology described here is predicated on the use of an existing baseline boost-glide transport design. A consistent set of mission, design, and operational parameters must be specified and sufficient supporting detail must be available to provide the technology specialists with a design definition. If an adequate level of detail is not available, then the Project Office must either arrange to have the material generated or must establish by ground rule, the values to be used.

The last input data requirement is the Project Objectives. The user must clearly understand the objective he is striving for so that he can properly inform and lead those he will ask to participate. The objective of this methodology is to provide a quantitative rationale to support the planning and allocation of resources for BGT technology. The results of the methodology are not intended to evaluate the economics of boost-glide vehicles nor to evaluate aircraft and operational procedures.

Procedures

This section presents the specific procedures to be followed by the Project Office in achieving the objective of the technology planning exercise. Each user will find some advantage in modifying these basic procedures to more exactly conform with his own view of the overall technology planning problem. The basic procedures are written so that a user with no prior experience in this area can easily use the methodology. Figure 1-2 is a flow chart of the various steps in the Procedures. Each step shown in figure 1-2 is explained in the following subsections.

Technological scenario.- The first step in the procedure is for the Project Office to prepare a "Technological Scenario." This scenario is to present a framework of perspectives and conditions within which the BGT technological developments may be assumed to occur. The specialists who will make the technology projections requested in Module 5 will need this background to put their projections in the proper context. An example of such a Technological Scenario is given as follows:

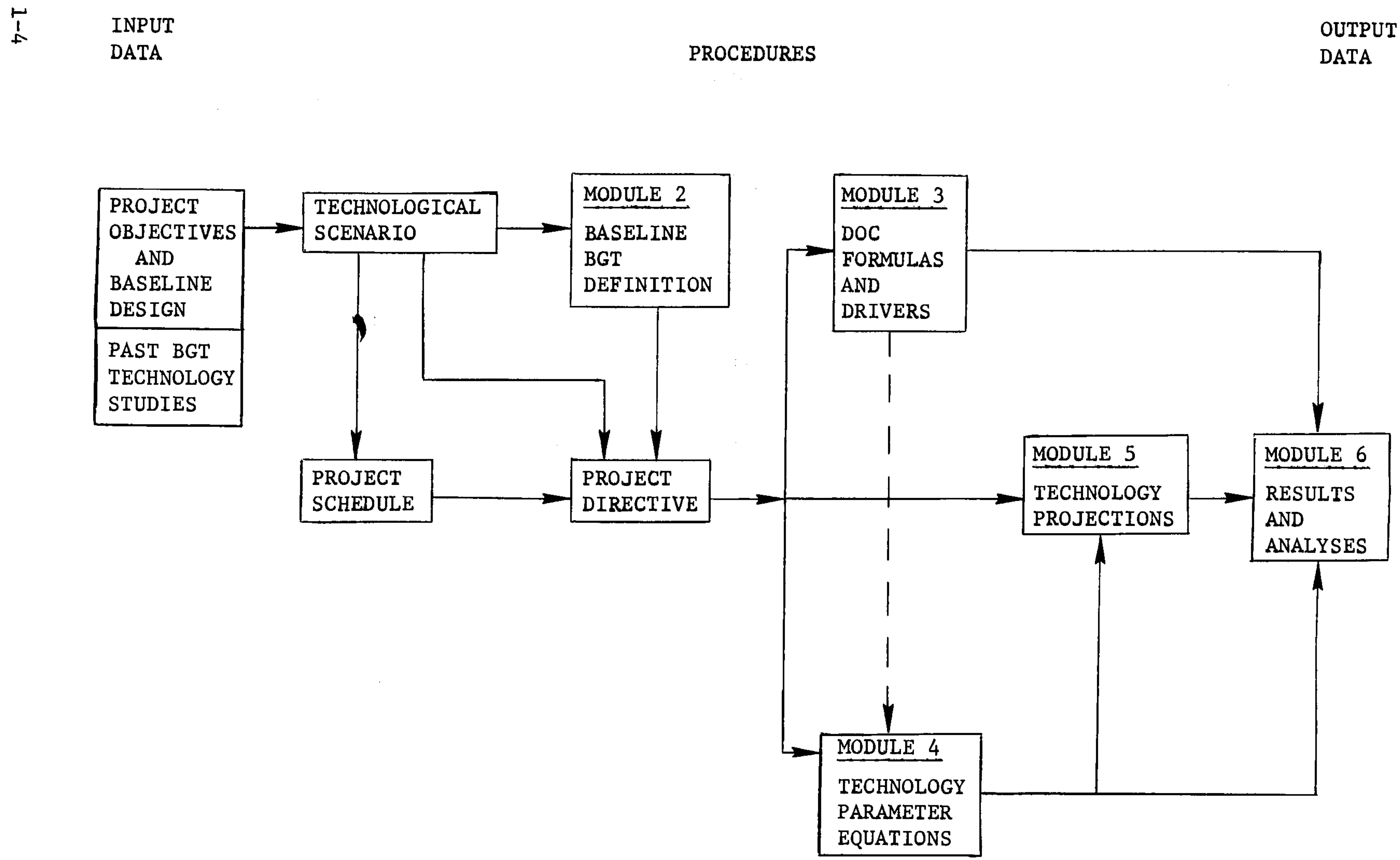


Figure 1-2.- Method Integration Flow Chart

Technological Scenario (Boost Glide)

By the early 80's, the Shuttle program will have demonstrated its promised economics of launch and reuse. A highly favorable public and government reaction to the airplane-like mode of flight into space will provide support for increased traffic and additional mission applications. During the mid-80's, the Shuttle will be flying routine missions to space, and post-flight refurbishment and pre-launch readiness operations will gravitate toward airline-types of practices. Technology will be accelerated to reduce recurring and operations cost through longer-life propulsion hardware and minimum maintenance thermal protection systems.

By the early 90's, turn-arounds within several hours and automated preflight checks and countdowns will be commonplace. Additional economics will be effected by reducing the amount and unit cost of the expendable hardware. With continued improvements in materials and flight technologies, the potential of an economic single-stage-to-orbit Shuttle will be seen to be a practical goal by the late 90's. Concurrently, the potential application of the technological and operational state-of-the-art to a boost-glide transport (BGT) will receive growing acceptance by the government. By the turn-of-the-century, an advanced Shuttle will demonstrate the practicability of flying boost-glide missions to any place on the earth's surface within a one hour block time. This position will be augmented by the availability of cheap power and low-cost propellants made possible by the introduction of fusion energy systems. The military and civil transportation implications of the demonstration will create a surge of support for a go-ahead of the BGT to be operational by the second decade of the new century.

Project schedule.- The Project Schedule relates the work to be done to the time period allotted and sets limits on each individual task. Figure 1-3 is an example Project Schedule with the recommended time periods for each task shown. Figure 1-3 can be used as is or modified by the Project Office for a particular schedule constraint. Generally, ten to twelve working days will be required to complete the method because of the need to transmit and receive written material between nonadjacent groups of people.

Baseline BGT definition.- As soon as the scenario and schedule are available, the Project Office will initiate work on Module 2, Baseline BGT Definition. Again, it is assumed that a consistent baseline BGT design, well documented, is available. Unless the Project Office is going to complete Module 2, it is recommended that this task be given to a systems analyst as opposed to a functional specialist. In any case, this module must be completed quickly since the output is required input for all the remaining modules. Information required to initiate the work of Module 2 includes identification of the BGT design to be the subject of the BGT baseline definition, identification of reference documents from which data are to be extracted, and identification of any special depth and technology emphasis desired.

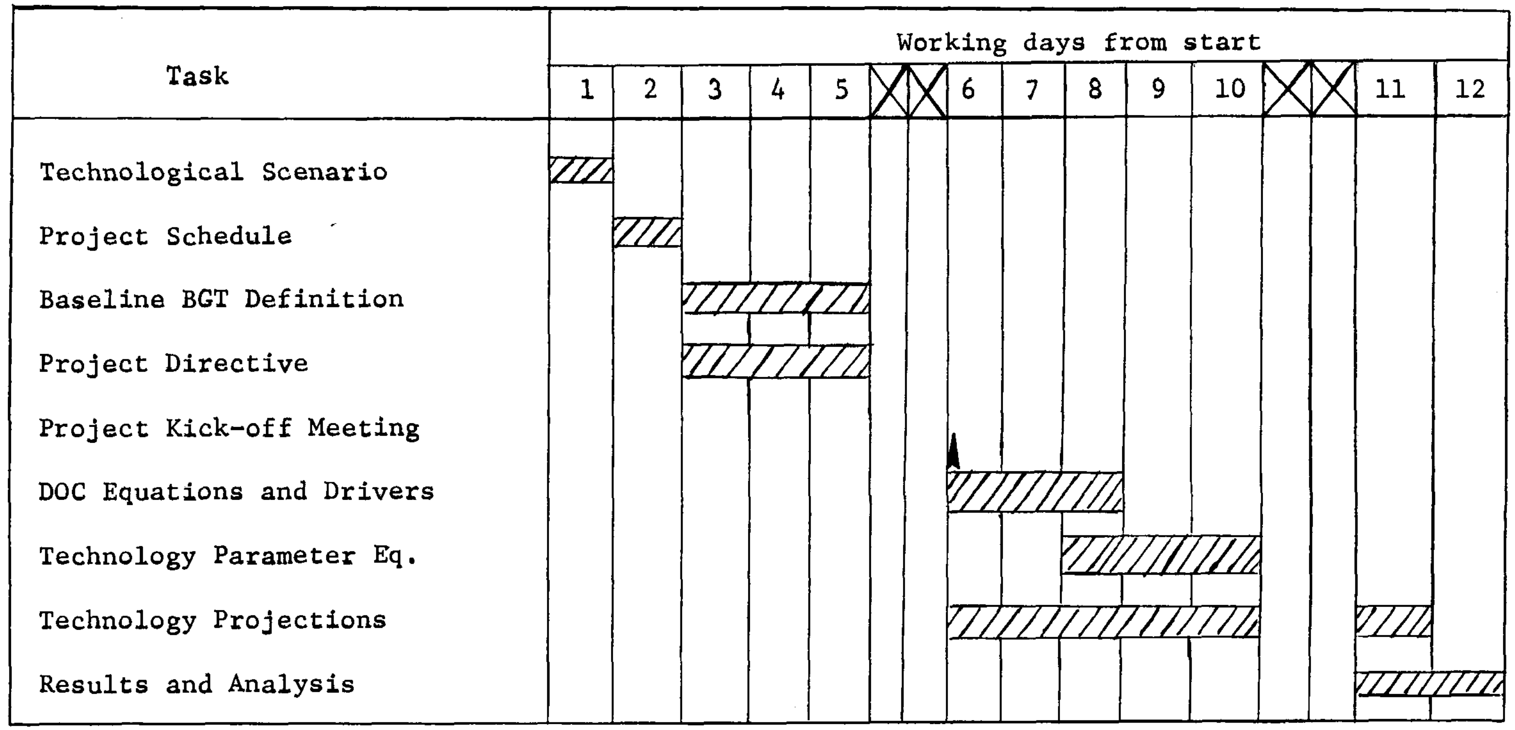


Figure 1-3.- Project Schedule

Project directive.- The Project Directive contains all the required instructions, schedules, data, and background required by the participants to do their jobs. It is the major output of the Method Integration Module and should be started as soon as the schedule is established. An example Project Directive Outline is given in Appendix 1-A.

The Project Directive should be distributed by the Project Office at a project kick-off meeting held on the sixth working day. The meeting would give all the participants a chance to ask questions and to assure schedule coordination. The participants must be chosen by the Project Office within the first few days and should include the analysts who will actually complete the modules as well as the technology specialists who will be responsible for the Technology Projections (Module 5).

DOC equations and drivers.- This is Module 3 which can be initiated immediately after the kick-off meeting by giving the responsible analyst a copy of Module 2 and the Projective Directive. The output of this module should be reviewed by the Project Office and should be coordinated with the analyst working with Module 4, Technology Parameter Equations.

Technology parameter equations.- Module 4 can be initiated immediately after the kick-off meeting. As before, the output should be reviewed by the Project Office and coordinated with Module 3.

Technology projections.- This is Module 5 and has potentially the longest time requirement. This module must be initiated immediately after the meeting. If possible, the Project Office should try to get the inputs earlier than shown in the schedule to allow some time for review and possible rework. Also, the specialists involved may not be in close proximity to the Project Office so some time delay in data transmittal must be expected.

Results and analyses.- The final module should be completed by the Project Office or at least closely monitored by the Project Office. The output of Module 6 is essentially the output of the methodology.

Summary

The methodology embodied in the six modules of this report can be a valuable tool when used together with the technology planner's normal data sources. The user is cautioned, however, not to use the results to make broad generalizations about the feasibility or economic viability of a BGT. The method must be applied judiciously and the results must be interpreted in the context of overall technology planning.

APPENDIX 1-A

EXAMPLE PROJECT DIRECTIVE OUTLINE

INTRODUCTION

This section should discuss the background and objectives of the project.

PROJECT SCHEDULE

Include the actual schedule and discuss the key dates for coordination, reproduction, distribution, etc. Include actual calendar dates on the schedule.

TECHNOLOGICAL SCENARIO

This section should give the reader an understanding of the projected environment for the BGT and its technology development. It should be in brief, narrative form as in the example given earlier.

BASELINE BGT DEFINITION

This section is the output section of Module 2, Baseline HST Definition.

GROUND RULES AND GUIDELINES

This section is optional and would include any additional parameters or constraints which the Project Office might impose.

BIBLIOGRAPHY

The Project Office should establish a recommended bibliography.

METHOD MODULE 2

BASELINE BGT DEFINITION

METHOD MODULE 2 - BASELINE BGT DEFINITION

Introduction

The methodology presented in this module for defining boost-glide transport vehicle baselines closely parallels that reported in Module 2 of reference 1 for definition of hypersonic transport vehicle baselines. In order to facilitate its use, the BGT methodology also is made complete--combining the similar portions from reference 1 with new items which are specifically related to the boost-glide transport.

Logic

The relative economic payoff of technology improvements is dependent upon the requirements and characteristics of the reference BGT baseline, e.g. - its mission, configuration, design features and technology state-of-the-art.

This module presents a mechanism for identifying and documenting the characteristics of BGT vehicle to form baselines for use in relative technology valuations.

The fundamental purpose of the "Baseline BGT Definition" module is to organize relevant data into a form useful to the DOC and technology modules of the overall procedure. In accomplishing this purpose the module utilizes information from previously or separately conducted studies. The process responds to ground rules and constraints which are a part of the initial input to this module.

The logic to be employed in the definition of BGT baselines is shown schematically in figure 2-1.

The baseline definition method is seen to consist of two major parts: information processing and documentation.

The purpose of the first part, information processing, is to form a complete, consistent package of data for use in the subsequent documentation. Basic steps are:

- o Acquisition of all relevant BGT data.
- o Screening to locate data applicable to the definition.
- o Collation of screened data for visibility and access.

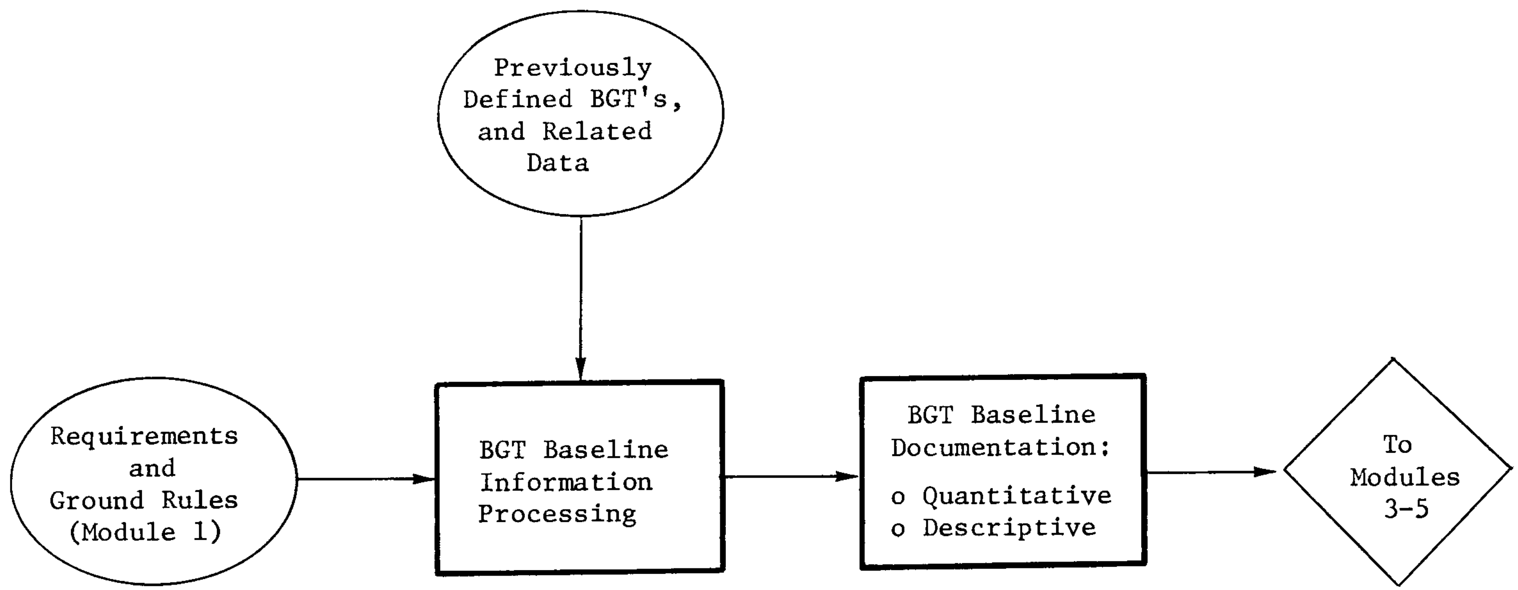


Figure 2-1.- Baseline Definition Logic Diagram

The purpose of the second part, documentation, is to prepare the baseline BGT definition output. The documentation consists of mission, operations, performance, design, weights and technology data. These data include:

- o Quantitative tabular data for use in the DOC and Technology Parameter equations, and technology projections.

- o Descriptive and quantitative data to fulfill other data needs and to provide an adequate understanding of the Baseline BGT and its technology state-of-the-art.

Formats and guidelines for preparing the BGT definition are included in the output data section. The formats for the quantitative tabular data give precisely the scope and depth of that portion of the information output. The descriptive summary of the baseline in the Demonstration section is an example of the scope and depth suggested for that portion of this module's information output.

Conditions and Qualifications

Consistent with the overall methodology and practices, the BGT baseline definition method applies specifically to hypersonic glide aircraft utilizing main rocket engines and employing vertical take-off and horizontal landing.

Within these limitations, the baseline definition method has the flexibility to accommodate mission and design variables, as summarized in the following table:

Variable category	Major alternatives accommodated
Payload	Cargo, passengers or combination
Burnout velocity	Up to orbital
Aero configuration	Blended wing-body, all-body or wing-body
Structure	Aluminum, titanium or other alloys; integral or non-integral tanks
Propellant type	Liquid propellants (LO_2/LH_2, LO_2/RP, etc.) and combinations
Propulsion	Single or dual-fuel rocket engines; parallel or sequential-burn Airbreathers for loiter/landing (optional)

Variations in payload type primarily affect the payload provisions and ground support equipment. Neither the baseline definition method nor the hypersonic technology requirements are impacted. Payload provision alternatives are passenger provisions vs cargo handling and tie-downs. Ground support is outside the scope of this definition method.

Variations in burnout velocity are accommodated by the method as demonstrated in this module plus the addition of a separate attitude control system and possibly deorbit provisions as burnout velocities approach orbital.

Lift-drag ratio, L/D, is the descriptor of aerodynamic performance in this method. Zero-lift drag coefficient C_{D_o} and induced drag factor $C_{D_i}/C_L{}^2$ are the aerodynamic Technology Parameters. All of the above definition items and parameters remain applicable whether the configuration is a blended wing-body, all body or conventional wing-body.

The output of the structures definition is expressed in weight fractions, associated Technology Parameter values, and supporting descriptions and conditions. Parameters in the method, therefore, accommodate variations in materials and in structural design primarily through their effects on weights. Additionally, Technology Parameters can reflect variations through the aggregate materials properties and design factors.

The definition method is the same for other propellant combinations, i.e., LO_2/RP as for LO_2/LH_2. Instructions for handling the case of more than one fuel type are included under "Procedures."

Instructions for handling the propulsion system variations accompanying the use of more than one fuel type also appears under "Procedures."

The method does not envision ~~the~~ use ~~of~~ active cooling of the structure as for the HST since the propellants which otherwise would constitute a major heat sink are expended during boost.

Input Data

As illustrated in the previous "Baseline Definition Logic Diagram," figure 2-1, two type of input data are required by this method module. One type, requirements and ground rules, is instructional; the other, BGT data, is informational.

Requirements and ground rules.- The requirements and ground rules, in conjunction with information in the referenced document(s), constrain the process in this module to the information processing and documentation activities. These instructional items, which are received by this module from Module 1, shall have the following general content:

(1) identification of the BGT design to be the subject of this baseline definition,

(2) identification of the reference document(s) from which the data required by this module should be extracted,

(3) any special depth and technology emphasis desired of descriptive data.

A sample requirements and ground rules input appears in the "Demonstration" section of this module.

BGT reference information.- As noted previously, the baseline BGT definition methodology operates upon existing information in preparing the BGT technical definition output. The information is required to support quantitative definition of the BGT vehicle, associated Technology Parameters and other qualifying characteristics.

Input data type required to support preparation of the module outputs include: mission, performance, operations, aerodynamics and propulsion, design and structures, weights and related technologies. Within these information categories, Table 2-I lists specific information items needed to quantify and subjects to qualify the BGT baseline definition.

Procedures

The procedures for defining and describing a baseline BGT are in two parts, (1) information processing and (2) documentation, consistent with the logic design, figure 2-1.

Information processing.- As noted earlier, the purpose of the information processing activities is to form a complete consistent package of readily retrievable data adequate for the needs of the subsequent documentation activities.

Information acquisition shall provide reasonable assurance that all BGT data relevant to the description of the desired baseline are available for use in this methodology. Information screening shall locate those BGT data within the acquired data base which support the baseline BGT definition needs. The screening criteria to be employed are: input data requirements as introduced in Table 2-I and expanded later under "Output Data." The degree of collation to be employed is at the discretion of the user of this method module since needs are dependent on the diversity of information sources encountered.

TABLE 2-I.- SPECIFIC DEFINITION ITEMS REQUIRING INFORMATION BASE

Input Information Types	Typical Definition Items Requiring Information Inputs
Mission definition	W_{PL}, V_{BO}, R_T Mission profile
Performance characteristics	L/D, I_{SP}, W_{BO}/GLOW
Operational characteristics	t_F, L_{TPS}, N_{FLTS}
Vehicle characteristics	Configuration; general arrangement $(W/S)_{LAND}$, $(W/A)_{TPS}$, A_{TPS}, N_{ME}, T_{ME}, $(T/W)_{GLOW}$, $(W/T)_{ME}$, N_{TJ}, T_{TJ}, Cruise C_D and C_L
Mass properties	Weight statement W_{AF}/GLOW
Design and structures description	Wing structure, materials Empennage structure, materials Fuselage structure, materials Tankage structure, materials Thermal protection system Main engine system Air-breathing propulsion system Equipment Avionics
Technology parameters	C_{D_o}, $C_{D_i}/{C_L}^2$, $(W/A)_{TPS}$, L_{TPS}, $(W/T)_{ME}$ FMP, WMP, I_{SP} Design factors, F

BGT baseline documentation.- The procedure for preparing the baseline documentation includes, as a first requisite, flexibility to accommodate major baseline variables. Next, the procedure provides for confirmation and/or adjustment of baseline values. Completion of the module outputs is the final step.

Accommodation of major variables: Flexibility built into the baseline definition method for accommodating mission and design variables has been summarized under "Conditions and Qualifications." Procedures for accommodating dual fuels and associated propulsion system variations are included here.

Options within the dual fuels alternative are:

A. Sequential burn/dual-fuel engines (engines which burn two types of fuel sequentially with one oxidizer)

B. Sequential burn/separate engines for each fuel

C. Parallel burn/separate engines for each fuel

Procedures are identified here for options A and C. Option B is considered unlikely because of the weight and cost penalties associated with not using all main engines at lift-off. Note that in option A, the sequencing is a fuel-type sequencing, not an engine use sequencing.

The procedure for including the dual fuels alternative is outlined using for illustration the case where both RP and LH_2 are employed. Steps which are common to sequential and parallel burn cases are:

1. Include RP and LH_2 separately in the weight statement.

2. List the mixture ratios (MR) for LO_2/RP and LO_2/LH_2 separately in the baseline data table.

3. List the ratio of LO_2/RP propellants used by main engines to total onboard propellants $\left(K_{P_1}\right)$ and the ratio of LO_2/LH_2 propellants used by main engines to total onboard propellants $\left(K_{P_2}\right)$ separately in the baseline data table.

For the sequential burn case, using dual-fuel engines (A), the subsequent steps are:

4. List main engine specific impulse (I_{SP} vacuum) separately for operation with LO_2/RP and LO_2/LH_2.

5. List main engine thrust (vacuum) per engine (T_{ME}) based on LO_2/LH_2 operation.

6. List main engine specific weight $(W/T)_{ME}$ based on T_{ME} for LO_2/LH_2 operation.

7. List thrust-to-weight ratio at lift-off $(T/W)_{GLOW}$ based on T_{ME} for LO_2/RP sea-level operation.

8. Apply the basic rocket equation separately to each propellant usage stage.

In the parallel burn case with separate engines for each fuel type (C), the use of F-1 engines for LO_2/RP and Shuttle main engines for LO_2/LH_2 is an example. All engines are employed at lift-off with the LO_2/RP being consumed and F-1 engines shut-down first. For this parallel burn case, steps 4-8 above are replaced by:

4. List main engine specific impulse (I_{SP} vacuum) separately for each engine type.

5. List main engine thrust (vacuum) per engine (T_{ME}) separately for each engine type.

6. List main engine specific weight $(W/T)_{ME}$ separately for each engine type.

7. List thrust-to-weight ratio at lift-off $(T/W)_{GLOW}$ where the thrust is the sum of the thrust at sea-level for all operating engines.

The average specific impulse for parallel burn is now found from the following:

$$\overline{I}_{SP} = \frac{\sum_i T_{ME_i}}{\sum_i \left(\frac{T_{ME_i}}{I_{SP_i}} \right)}$$

When mixed propulsion systems and parallel burn are employed, this is the value that should be used in the equations given later for range.

Other BGT characteristics for the preceding alternatives may be listed using the normal procedures in this method.

Confirmation or adjustment of baseline values: This step in the procedure includes the following:

- o Check input values, including range, to assure compatibility with methods for later determination of partials and sensitivities.
- o Reconstitute weight statement, as required, to support the quantifying of weight parameters. (See Table 2-X in Demonstration section.)
- o Calculate dependent parameters, as required, e.g., - weight fractions from weight statement.

Range may be confirmed or adjusted using the following procedure. (Note: all inputs to equations in SI units.)

Ideal velocity, $\Delta V_I = I_{SP} \ \ell n \left(\frac{GLOW}{W_{BO}}\right)$

Burnout velocity, $V_{BO} = \frac{\Delta V_I}{A} - B$

where A and B account for ascent trajectory losses.

$$V_{BO} = \frac{I_{SP}}{A} \ \ell n \left(\frac{GLOW}{W_{BO}}\right) - B, \quad \text{m/sec}$$

To account for the earth's rotation, take:

$$V'_{BO} = V_{BO} + \sin \phi \ \cos\theta \ V_{R_\oplus} \ F$$

where

ϕ = azimuth (East = 90°, West = 270°)

θ = latitude (Equator = 0°, Pole = 90°)

$V_{R_\oplus}$ = 457 m/sec

F = 2/3 ...... an empirical factor

Ascent range : $R_A = \frac{(V_{BO})^2}{2\ a_g n} \left(\frac{1}{1000}\right)$, km

For

n = maximum acceleration in g's = 2

$$R_A = 25.47 \left(\frac{V_{BO}}{1000}\right)^2 \quad \text{km}$$

Cruise range: Post-boost propulsion provides the following increment:

$$R_C = \frac{C\ V_{BO} I_{SP}}{9806} \left(\frac{W'_P}{W_{BO} - 0.5\ W'_P}\right) \left[\frac{L/D}{1 - \left(\frac{V''_{BO}}{V_S}\right)^2}\right], \text{ km}$$

This expression represents the range that would be traversed during the time Δt that the post-boost propulsion would burn at thrust sufficient to sustain V_{BO}, ... corrected by a factor C. This factor corrects for the condition where post-boost engine thrust is less than that required to sustain V_{BO}.

The expression for R_C is derived as follows :

$$R_C = C\ V_{BO}\ \Delta t$$

Expressing the post-boost propellant weight as $\dot{W}'_P$

$$\Delta t = \frac{W'_P}{\dot{w}} = \frac{W'_P}{T_S/I_{SP}} = \frac{W'_P\ I_{SP}}{T_S}$$

where

T_S = thrust (average) to sustain V_{BO}

$$= (9.806)\ (W_{BO} - 0.5\ W'_P) \left[\frac{1 - \left(\frac{V''_{BO}}{V_S}\right)^2}{L/D}\right]$$

where

$$V''_{BO} = V_{BO} + \sin \emptyset \ \cos \theta \ V_{R_\oplus}$$

The cruise range then is

$$R_C = \frac{C\ V_{BO}}{9.806} \left\{ \frac{W'_P \quad I_{SP}}{\left(W_{BO} - 0.5\ W'_P\right) \left[\frac{1 - \left(\frac{V''_{BO}}{V_S}\right)^2}{L/D}\right]} \right\}, \text{ m}$$

<u>Glide range</u>: $R_G = K \frac{R_\oplus}{2} \left(\frac{L}{D}\right) \ \ln \left[\frac{1}{1 - \left(V'_{BO}/V_S\right)^2}\right]$

For

$R_\oplus$ = radius of Earth = 6371.2 km

K = correction for ripple trajectory = 1.10

V_S = orbital velocity at burnout altitude
= 7833 m/sec at 91,440 m

the glide range is

$$R_G = (1.1)\ (3185.6) \left(\frac{L}{D}\right) \ \ln \left[\frac{1}{1 - \left(V'_{BO}/7833\right)^2}\right], \text{ km}$$

Descent and landing range: The range increment for final descent and landing approach is approximately

$$R_{D\&L} = 65 \text{ km } (40 \text{ s. mi.})$$

Total operational range, the summation of components, is

$$R_T = R_A + R_C + R_G + R_{D\&L}$$

Preparation of output data packages: The baseline definition items and technology parameter summaries, Tables 2-II and 2-III in the "Output Data" portion of this method shall then be completed. The descriptive summary of the baseline BGT shall also be prepared in accordance with the guidelines and outline, Table 2-IV. The completed output is to be distributed to the companion modules of this overall procedure by the Project Office.

Output Data

The output of the baseline BGT definition method module shall be:

- o A set of tabular data prepared using the forms contained in this section.
- o A summary description of the baseline prepared in accordance with the guidelines contained in this section.

Tabular data for DOC and Technology Parameter equations.- Table 2-II presents the information items and format to be employed in preparing the portion of the definition required for the DOC equations, Module No. 3, and for use in the technology modules, numbers 4 and 5. Six of the information items, identified by asterisks (*) in Table 2-II are defined as Drivers of direct operating cost.

Tabular summary of Technology Parameters.- Table 2-III identifies the Technology Parameters that relate to and impact the DOC Drivers. The table also provides the format to be employed in quantifying these Technology Parameters as a part of this baseline definition. The table is an output for use in Module No. 4.

TABLE 2-II.- BASELINE DATA FOR DOC AND TECHNOLOGY PARAMETER EQUATIONS

Baseline characteristics	Baseline Values	
	SI units	English units
Mission/performance		
Operational range, R_T	km	n. mi.
*Hypersonic lift-drag ratio, L/D		
*Main engine specific impulse, $(I_{SP})_{vacuum}$	N-sec/kg	$\frac{lb_f\text{-sec}}{lb_m}$
Operations		
Time of flight, t_F		
*Thermal protection system life, L_{TPS}		
Flight cycles during depreciable life, N_{FLTS}		
Vehicle characteristics		
*TPS average weight per unit area, $(W/A)_{TPS}$	kg/m^2	lb/ft^2
Total area of surface protected by TPS, A_{TPS}	m^2	ft^2
Area protected by TPS against temp T_i, A_i	m^2	ft^2
Maximum temperature of surface area A_i, T_i	K	°F
*Main engine specific weight, $(W/T)_{ME}$	kg/N	
Number of main engines, N_{ME}		
Main engine thrust (vacuum) per engine, T_{ME}	N	lb
Thrust-to-weight ratio at lift-off, $(T/W)_{GLOW}$	N/kg	

*DOC Drivers

TABLE 2-II.- BASELINE DATA FOR DOC AND TECHNOLOGY PARAMETER EQUATIONS - Concluded

Baseline characteristics	Baseline Values	
	SI units	English units
Vehicle characteristics - cont.		
ME mixture ratio (LO_2/LH_2) by weight, MR		
Number of turbojet engines, N_{TJ}		
Turbojet thrust (SL static) per engine, T_{TJ}	N	lb
Weight characteristics		
Gross lift-off weight, GLOW	kg	lb
*Airframe weight fraction, W_{AF}/GLOW		
Structure weight fraction, W_S/GLOW		
Equipment weight fraction, W_{Eq}/GLOW		
Avionics weight fraction, W_{AV}/GLOW		
Payload weight fraction, W_{PL}/GLOW		
Total onboard propellant weight fraction, W_{P_T}/GLOW		
Ratio of ME propellants to total onboard, K_P		
Airframe weight, W_{AF}	kg	lb
Weight ratio, wing to airframe, W_W/W_{AF}		
Weight ratio, empennage to airframe, W_E/W_{AF}		
Weight ratio, body to airframe, W_B/W_{AF}		
Weight ratio, propellant tanks and system to airframe, W_{PTS}/W_{AF}(a)		
Weight ratio, other systems to airframe, W_{OS}/W_{AF}(b)		

*DOC Drivers; (a) $W_{PTS} = W_T + W_{INS} + W_{PS}$; (b) $W_{OS} = W_{EQ} - W_{PS}$

TABLE 2-III.- TECHNOLOGY PARAMETERS - REQUIRED OUTPUTS FROM MODULE 2

Technology Parameter		Baseline Value
Aerodynamics		
C_{D_o}	zero-lift drag coefficient	
C_{D_i}/C_L^2	induced drag factor	
Aggregate material properties		
FMP	fuselage material properties	
WMP	wing material properties	
Airframe design		
$F_{W,B}$	design factor for wing structure designed by buckling criteria	
$F_{W,C}$	design factor for wing structure designed by crippling criteria	
$F_{W,S}$	design factor for wing structure designed by stiffness criteria	
$F_{W,Y}$	design factor for wing structure designed by yield criteria	
$F_{W,F}$	design factor for wing structure not designed by primary loads	
$F_{F,B}$	design factor for fuselage structure designed by buckling criteria	
$F_{F,C}$	design factor for fuselage structure designed by crippling criteria	
$F_{F,S}$	design factor for fuselage structure designed by stiffness criteria	

TABLE 2-III.- TECHNOLOGY PARAMETERS - REQUIRED OUTPUTS FROM MODULE 2 - Concluded

Technology Parameter		Baseline Value
$F_{F,Y}$	design factor for fuselage structure designed by yield criteria	
$F_{F,F}$	design factor for fuselage structure not designed by primary loads	
F_E	design factor for empennage weight	
F_P	design factor for propellant system weight	

TABLE 2-IV.- DESCRIPTIVE INFORMATION SUBJECTS

<u>Mission</u>

- o Nature of payload
- o Flight profile

<u>Performance</u>

- o Conditions in defining range

<u>Operational characteristics</u>

- o Flight and block times during depreciable life
- o Ground time available for turnaround

<u>Vehicle characteristics</u>

- o Configuration and general arrangement
- o Aerodynamic characteristics
- o Weight summary
- o Structure
- o Thermal protection system
- o Main engine system
- o Air-breathing propulsion system
- o Equipment
- o Avionics
- o Payload provisions

Descriptive summary of baseline.- The descriptive summary of the BGT baseline is complementary to the tabular summaries. The method outlined herein for preparation of this complementary output offers sufficient flexibility in preparing information content to accommodate special areas of technical interest within the overall descriptive framework. Guidelines are of two categories: (1) information subject and organization guidelines, and (2) guidelines for describing information subjects.

Information subject and organization guidelines: Major information subjects and their recommended organization in this descriptive summary are presented in Table 2-IV. The organization facilitates relation to the baseline characteristics of Table 2-II and Technology Parameters in Table 2-III.

Guidelines for describing information subject: Because descriptive information needs vary among the subjects listed in Table 2-IV, the following are offered as general guidelines.

- o The descriptive summary should identify baseline information sources used.
- o The descriptions should summarize conditions and assumptions basic to values of baseline definition items in Tables 2-II and 2-III.
- o The descriptions should provide indicators of the technology level of the baseline BGT.
- o The descriptive summary should be concise; information should be selective with references noted where expanded data are available.

DEMONSTRATION

This section illustrates the implementation of the baseline definition methodology in defining and describing a BGT technical baseline. The baseline BGT output in this example is that employed as a reference in the overall procedure of which this module is a part.

Requirements and Ground Rules

As indicated in the logic diagram, figure 2-1, in the preceding "Baseline Definition Methodology" section, the BGT baseline definition activity is initiated upon receipt of a set of requirements and ground rules from Method Module 1.

Basic requirements and ground rules for this demonstration are presented in Table 2-V.

Because a suitable BGT baseline was not available from the literature, these ground rules required the separate generation of a BGT baseline. The baseline generation methodology employed is outside the scope of this method module and is not reported herein. This demonstration, therefore, summarizes BGT data supplied by the baseline generation activity for use in the overall procedure.

Information Processing and Documentation

Upon completion of prior steps in the information definition process, confirmation or adjustment of baseline values is performed. As a last step, operational range is calculated. Burnout velocity is calculated from the formula,

$$V_{BO} = \frac{I_{SP}}{A} \ \ell n \left(\frac{GLOW}{W_{BO}}\right) - B$$

where A and B account for ascent trajectory losses.

$$V_{BO} = \frac{4560}{1.064} \ \ell n \left(\frac{1\ 814\ 400}{287\ 100}\right) - 1389$$

$$= 6520 \text{ m/sec} \quad (21,391 \text{ ft/sec})$$

TABLE 2-V.- BASELINE BGT REQUIREMENTS AND GROUND RULES

Mission and operational requirements

Payload of approximately 18 100 kg (40 000 lb) an objective
Semi-global (anti-podal) range an objective
Operational time period: post-2000
Operational load factor of 60 percent
Airframe depreciable life of 10 years

Flight requirements

Vertical take-off, horizontal landing
VTO to safe flight conditions (no expendable hardware)
2g acceleration limit
Near-equilibrium glide profile
Loiter range of 278 km (173 s. mi.)

Vehicle

Gross lift-off weight of about 1 814 000 kg (4 000 000 lb)
Airframe (wing, empennage and body) of aluminum alloy
Airframe unit weights: 25 percent improvement from Shuttle
Propellants: LO_2 and LH_2 at mixture ratio of 6.0
Propellant tanks : aluminum alloy
Propellant tank weights based on Shuttle external tank
Fully reusable TPS replaceable after 500 flights
TPS unit weights to be developed from Shuttle data
Crew and payload provisions weights to be developed from HST data, reference 1

Propulsion

Main engines: sea-level thrust of 1 856 000 N (417 300 lb)
Vacuum specific impulse of 4560 N-sec/kg (465 (lb_f-sec)/lb_m)
LH_2-fueled turbojets sized for loiter/cruise
"Bolt-on" turbojet modules for ferry per Shuttle phase B'

Technology state-of-the-art

Advanced post-Shuttle technology; natural follow-on to Shuttle

V'_{BO}, calculated for a due-East launch at the equator using the formula,

$$V'_{BO} = V_{BO} + \sin \phi \cos \theta \, V_{R_\oplus} \quad F$$

is

$$V'_{BO} = 6520 + (1)\ (1)\ 457\ (2/3)$$

$$= 6825 \text{ m/sec } (22\ 391 \text{ ft/sec})$$

and

$$V''_{BO} = 6977 \text{ m/sec } (22\ 900 \text{ ft/sec})$$

Ascent range, calculated from the formula

$$R_A = 25.47 \left(\frac{V_{BO}}{1000}\right)^2$$

is

$$R_A = 25.47 \left(\frac{6520}{1000}\right)^2 = 1083 \text{ km } (673 \text{ s. mi.})$$

The cruise range component contributed by post-boost propulsion, calculated by the formula,

$$R_C = \frac{C\, V_{BO} I_{SP}}{9806} \left(\frac{W'_P}{W_{BO} - 0.5\, W'_P}\right) \left[\frac{L/D}{1 - \left(\frac{V''_{BO}}{V_S}\right)^2}\right]$$

is

$$R_C = \frac{0.86\ (6520)\ 4560}{9806} \left(\frac{7711}{287\ 130 - 3855}\right) \left[\frac{3}{1 - \left(\frac{6977}{7833}\right)^2}\right]$$

$$= 1031 \text{ km } (641 \text{ s. mi.})$$

Basic glide range, calculated from the formula,

$$R_G = K\ 3185.6 \left(\frac{L}{D}\right) \ \ln \left[\frac{1}{1 - (V'_{BO}/7833)^2}\right]$$

is

$$R_G = K\ 3185.6 \ \ (3) \ \ \ln \left[\frac{1}{1 - (6825/7833)^2}\right]$$

$$= K\ 13\ 646\ \text{km}\ (8479\ \text{s. mi.})$$

This range increases by about 10% if a ripple trajectory is used (K = 1.10):

$$R_G = 15\ 011\ \text{km} \quad (9328\ \text{s. mi.})$$

The range increment for final descent and landing is

$$R_{D\&L} = 65\ \text{km}\ (40\ \text{s. mi.})$$

Total operational range from

$$R_T = R_A + R_C + R_G + R_{D\&L}$$

is

$$R_T = 1083 + 1031 + 15\ 011 + 65 = 17\ 190\ \text{km} \ \ (10\ 680\ \text{s. mi.})$$

Upon completion of this last step in the baseline identification process, a full information package is available for use in preparing the required BGT documentation.

Tabular Documentation of Baseline

Quantitative BGT data for DOC and Technology Parameter equations.- Table 2-VI presents the quantitative characteristics of the baseline BGT as required by the terms within the Technology Parameter and DOC equations (including the DOC Drivers). The format is that specified by Table 2-II in the "Methodology" section.

Technology Parameters.- Table 2-VII presents the baseline values for the Technology Parameters using the format from Table 2-III of the "Methodology" section.

TABLE 2-VI.- BASELINE DATA FOR DOC AND TECHNOLOGY PARAMETER EQUATIONS

Baseline characteristics	Baseline Values	
	SI units	English units
Mission/performance		
Operational range, R_T	17 190 km	10 680 s. mi.
*Hypersonic lift-drag ratio, L/D	3.0	3.0
*Main engine specific impulse, $(I_{SP})_{vacuum}$	4560 N-sec/kg	465 $\frac{lb_f\text{-sec}}{lb_m}$
Operations		
Time of flight, t_F	1.40 hr	1.40 hr
*Thermal protection system life, L_{TPS}	500	500
Flight cycles during depreciable life, N_{FLTS}	7140	7140
Vehicle characteristics		
*TPS average weight per unit area, $(W/A)_{TPS}$	5.088 kg/m^2	1.089 lb/ft^2
Total area of surface protected by TPS, A_{TPS}	4653 m^2	47 920 ft^2
Area protected by TPS against temp T_i, A_i	(a) m^2	(a) ft^2
Maximum temperature of surface area A_i, T_i	(a) K	(a) °F
*Main engine specific weight, $(W/T)_{ME}$	0.00137 kg/N	0.01347
Number of main engines, N_{ME}	12	12
Main engine thrust (vacuum) per engine, T_{ME}	1 856 000 N	417 300 lb
Thrust-to-weight ratio at lift-off, $(T/W)_{GLOW}$	12.28 N/kg	1.252
ME mixture ratio (LO_2/LH_2) by weight, MR	6.0	6.0

*DOC Drivers

(a) Developed in Module 3

TABLE 2-VI.- BASELINE DATA FOR DOC AND TECHNOLOGY PARAMETER EQUATIONS - Concluded

Baseline characteristics	Baseline Values SI units	Baseline Values English units
Vehicle characteristics - cont.		
Number of turbojet engines, N_{TJ}	4	4
Turbojet thrust (SL static) per engine, T_{TJ}	200 200 N	45 000 lb
Weight characteristics		
Gross lift-off weight, GLOW	1 814 400 kg	4 000 000 lb
*Airframe weight fraction, $W_{AF}/GLOW$	0.0815	0.0815
Structure weight fraction, $W_S/GLOW$	0.0628	0.0628
Equipment weight fraction, $W_{Eq}/GLOW$	0.0187	0.0187
Avionics weight fraction, $W_{AV}/GLOW$	0.0010	0.0010
Payload weight fraction, $W_{PL}/GLOW$	0.0105	0.0105
Total onboard propellant weight fraction, $W_{P_T}/GLOW$	0.8417	0.8417
Ratio of ME propellants to total onboard, K_P	0.977	0.977
Airframe weight, W_{AF}	147 950 kg	326 180 lb
Weight ratio, wing to airframe, W_W/W_{AF}	0.1111	0.1111
Weight ratio, empennage to airframe, W_E/W_{AF}	0.0346	0.0346
Weight ratio, body to airframe, W_B/W_{AF}	0.3396	0.3396
Weight ratio, propellant tanks and system to airframe, W_{PTS}/W_{AF}	0.3574	0.3574
Weight ratio, other systems to airframe, W_{OS}/W_{AF}	0.1573	0.1573

*DOC Drivers

TABLE 2-VII.- TECHNOLOGY PARAMETERS

Technology Parameter		Baseline Value
Aerodynamics		
C_{D_o}	zero-lift drag coefficient	0.0149
C_{D_i}/C_L^2	induced drag factor	1.62
Aggregate material properties		
FMP	fuselage material properties	(a)
WMP	wing material properties	(a)
Airframe design		
$F_{W,B}$	design factor for wing structure designed by buckling criteria	1.00
$F_{W,C}$	design factor for wing structure designed by crippling criteria	1.00
$F_{W,S}$	design factor for wing structure designed by stiffness criteria	1.00
$F_{W,Y}$	design factor for wing structure designed by yield criteria	1.00
$F_{W,F}$	design factor for wing structure not designed by primary loads	1.00
$F_{F,B}$	design factor for fuselage structure designed by buckling criteria	1.00
$F_{F,C}$	design factor for fuselage structure designed by crippling criteria	1.00
$F_{F,S}$	design factor for fuselage structure designed by stiffness criteria	1.00

(a) - Values to be developed in Module 4, "Technology Parameter Equations."

TABLE 2-VII.- TECHNOLOGY PARAMETERS - Concluded

	Technology Parameter	Baseline Value
$F_{F,Y}$	design factor for fuselage structure designed by yield criteria	1.00
$F_{F,F}$	design factor for fuselage structure not designed by primary loads	1.00
F_E	design factor for empennage weight	1.00
F_P	design factor for propellant system weight	1.00

Descriptive Summary of Baseline

This descriptive summary of the baseline BGT follows the outline in Table 2-IV and responds to the associated guidelines given in the "Methodology" section. Summary characteristics of this baseline BGT are presented in Table 2-VIII.

Mission.- The mission of the baseline BGT is to transport payloads of 19 050 kg (42 000 lb) to destinations corresponding in range to 17 190 km (10 680 s. mi.). The BGT is to operate routinely and safely as a commercial transport aircraft over international routes.

The BGT is to have the flexibility of carrying either passengers or cargo, with payload-peculiar modifications being limited to the payload compartment and payload provisions. The basic economic analysis in Module 3 assumes a cargo payload, and direct operating costs are expressed in cents per ton-mile. The procedure for converting to cents per passenger-mile is also given in Module 3.

The flight profile for the baseline mission is shown in figure 2-2. Following vertical launch, the glide vehicle is accelerated to its maximum velocity at a main engine burnout altitude of 67 060 m (220 000 ft). The glide (and cruise) path is defined as that portion of the flight path along which the vehicle decelerates from amin engine burnout conditions to a glide velocity of 366 m/sec (1200 ft/sec). The terminal segment of the flight path is that traversed during the final descent and landing approach. The ascent phase contributes about 6.4 per cent of the range, the glide (and cruise) phases cover about 93.2 per cent, and the final descent and landing approach about 0.4 per cent of the total range.

Total flight time is 1.40 hours for the baseline mission. Allowing 0.10 hours for ground-taxi after touch-down yields a total mission time of 1.5 hours.

Performance.- BGT performance is summarized in the flight profile, figure 2-2, and in the confirmation of range on pages 2-18, 2-20, and 2-21. Primary input values upon which the performance is based appear in the confirmation. Other conditions and/or assumptions which contribute to the performance definition are summaried in the following listing:

Short vertical boost phase followed by programed pitchdown maneuver.

Sequential engine throttling and shutdown to hold limit acceleration to 2g.

TABLE 2-VIII.- BASELINE BGT SUMMARY CHARACTERISTICS

Mission and operations

Payload weight	19 050 kg (42 000 lb)
Payload volume	549 m^3 (19 400 ft^3)
Passenger seats	195
Total range for due-East launch	17 190 km (10 680 s. mi.)
Block time	1.5 hr
Flight cycles during depreciable life	7143

Vehicle

Aerodynamic configuration: double-delta, low-wing blended with flat underside of modified, elliptical, homothetic body; elevons plus canard for subsonic only; single vertical with split rudder/speed brake.

General arrangement: hybrid integral LH_2 multicell tank forward; LO_2 multicell tank integrated with wing carry-through and "multicell" payload compartment; propulsion section aft.

Main engines: twelve main engines improved from Shuttle Orbiter

Post-ascent engines: two Space Tug-type engines

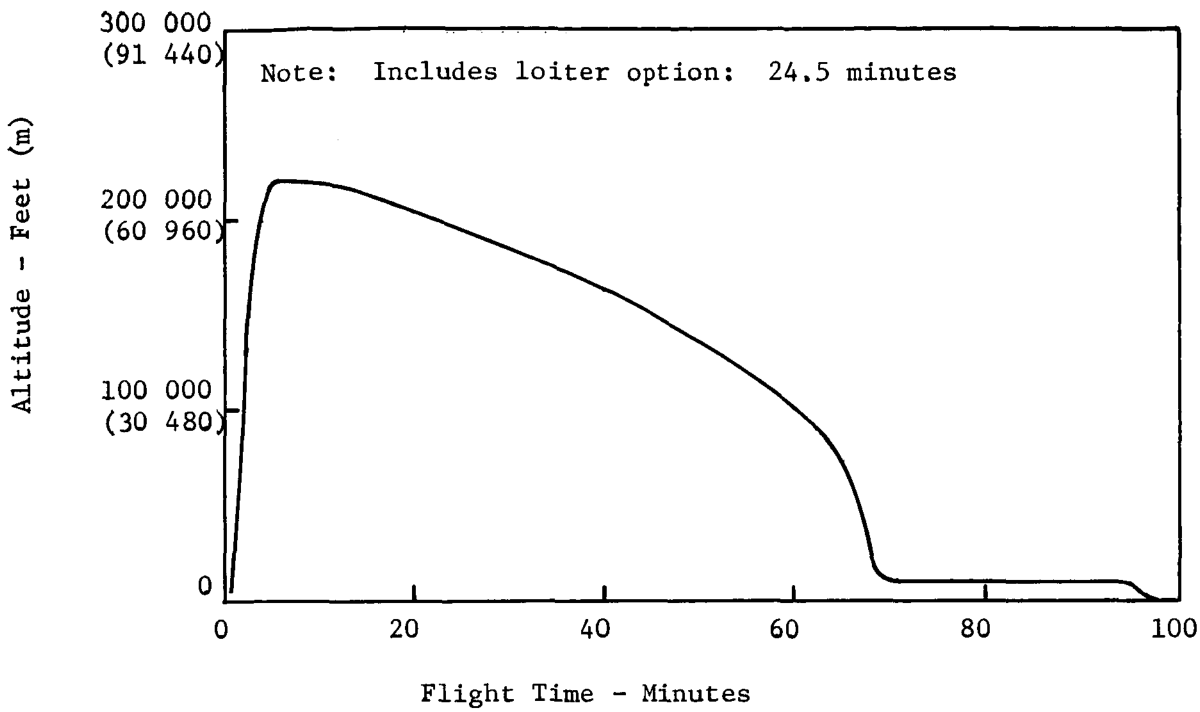
Loiter/landing engines: four hydrogen-fueled nonaugmented turbojets

Design and structures

Wing : thermally protected aluminum alloy multispar
Vertical tail: thermally protected aluminum alloy
Fuselage: thermally protected aluminum alloy
Propellant tanks: aluminum alloy multicell tanks integrated with fuselage and carry-through in a hybrid configuration
Thermal protection system: ceramic and elastomeric reusable surface insulation; reinforced carbon-carbon in wing leading edge and body nose cap
Propulsion section: lightly-loaded external structure; large access panels; swing-out inlets for turbojet engines

Weight

Gross take-off weight	1 814 400 kg (4 000 000 lb)
Landing weight	277 610 kg (612 000 lb)
Dry weight	243 600 kg (537 000 lb)



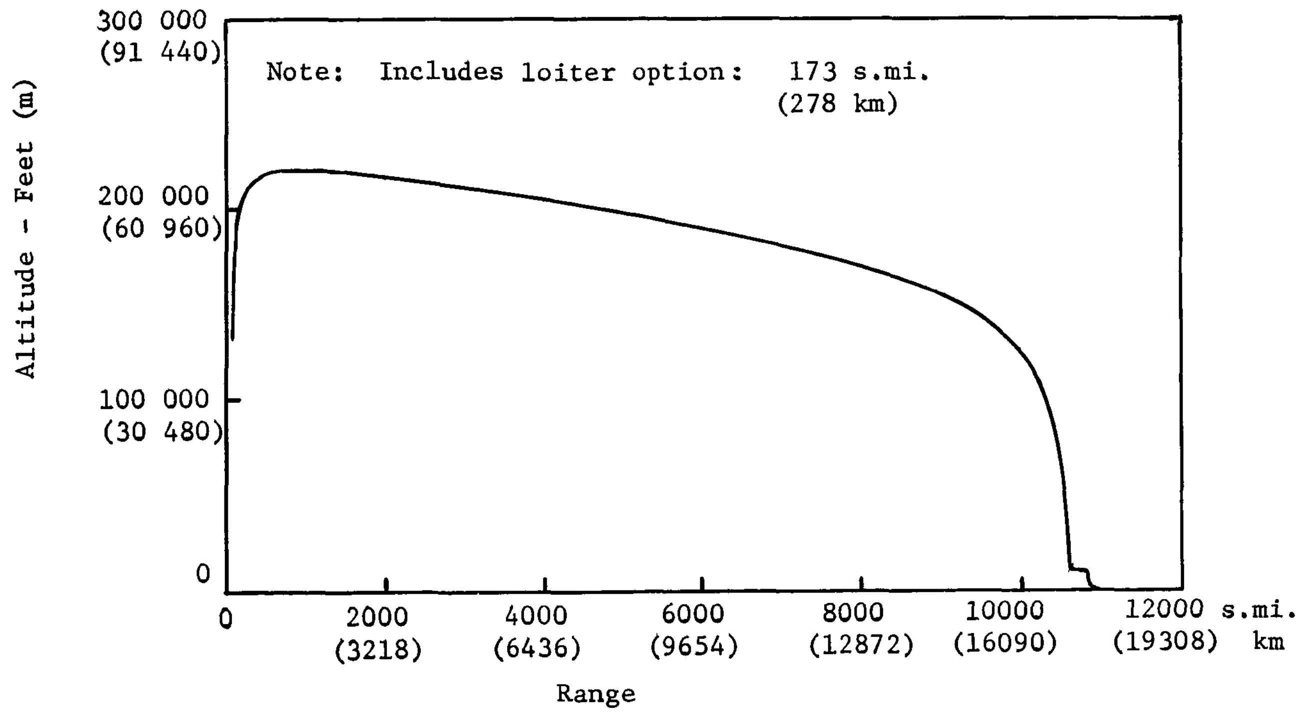


Figure 2-2.- Flight Profile

Main engine burnout at zero flight path angle and at altitude for commencement of glide (or cruise).

Propellant mass fraction of 0.8352 usable by main engines.

Propellant mass fraction of 0.02685 (based on W_{BO}) usable by post-ascent engines.

Hypersonic lift-drag ratio of 3.0 assumed to be constant throughout glide descent.

Subsonic lift-drag ratio of about 5.0.

Operational characteristics.- Factors which define BGT utilization are summarized in the following tabulation.

Time of flight, t_F = 1.4 hr

Block time, t_B = 1.5 hr

Average utilization, U = 1000 flight hr/yr

Depreciable life, L_d = 10 yr

Utilization during depreciable life = 10 000 flight hr
= 10 714 block hr

Non-utilization during depreciable life = 76 886 hr

Flight cycles during depreciable life = 7143

Total number of seats = 200

Number of passenger seats = 195

Average load factor = 0.60

Configuration and general arrangement.- The general arrangement of the baseline BGT is shown in figure 2-3.

Body: The baseline design employs a homothetic (constant cross-sectional shape) body. This body cross-section has been developed by NASA/LRC from a basic cross-section having an elipticity of 2.0. The combination of a flat undersurface and inward sloping side surfaces yields favorable hypersonic lift-drag characteristics and reduces heat loads on the side surfaces. A high-fineness ratio nose (0.833 times body length) contributes

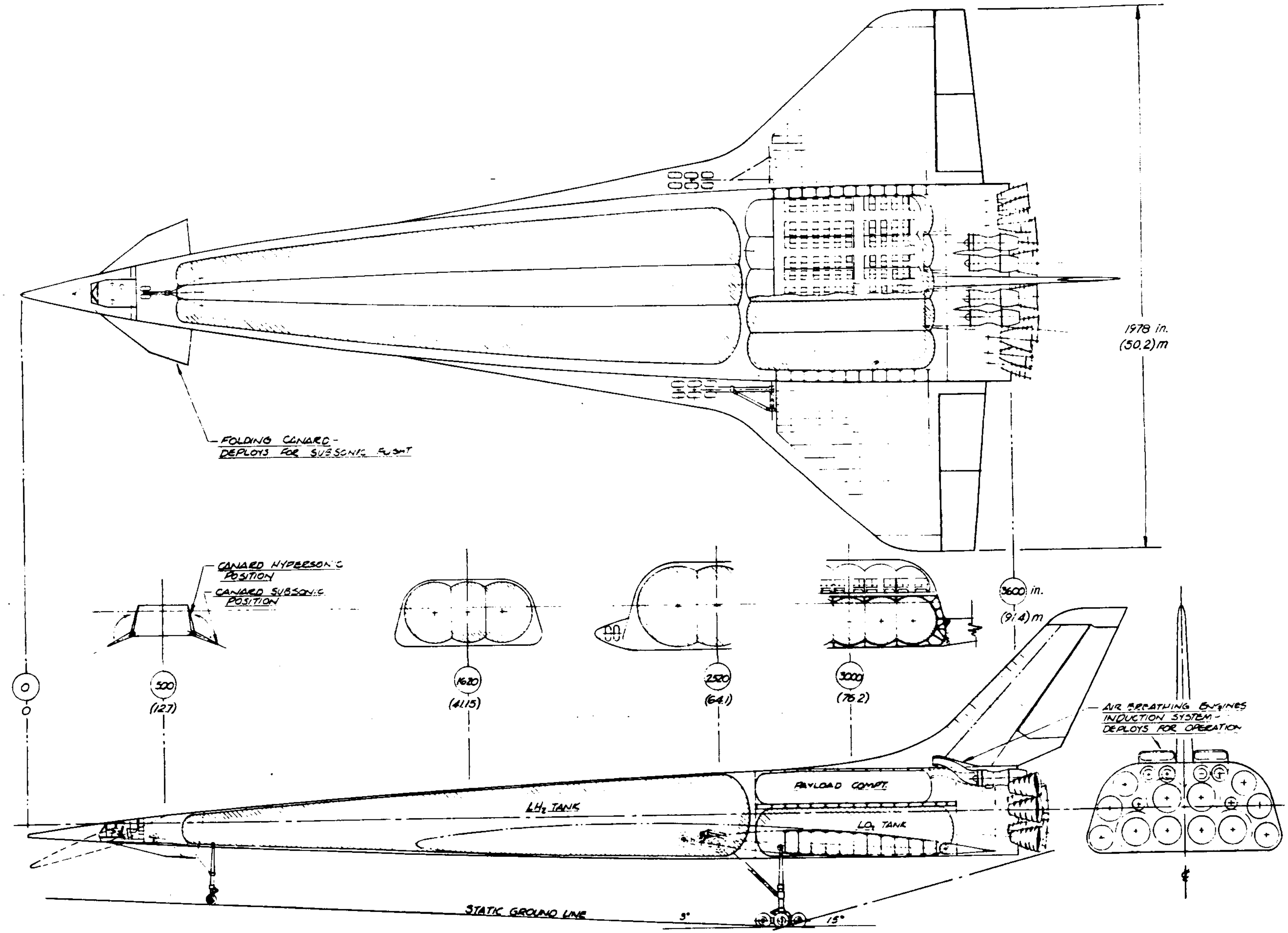


Figure 2-3.- Baseline Boost-Glide Transport

to the attainment of a hypersonic lift-drag ratio of 3.0. Nose camber improves hypersonic pitch trim.

Wing: The double delta wing planform was selected based on Shuttle phase C findings. Basically, the double delta (1) extends the useful angle of attack range, i.e. - postpones stall, (2) linearizes the pitching moment characteristic at low speed, (3) also reduces the shift of the aerodynamic center with Mach number, and (4) further shields the sides of the fuselage from high heating. The planform of the basic wing (neglecting the forward glove) has an aspect ratio of 2.265 and taper ratio of 0.2 as does the Shuttle. Full-span elevons are the primary aerodynamic means of developing pitch and roll control forces.

Canard surface: A canard control surface, which is stowed flush with the forward body side surface during hypersonic and supersonic flight, is deployed as a control and lift augmentation device for subsonic flight only. The canard control surface can increase elevons effectiveness by reducing the BGT stability margin when deployed. The canard also augments the elevons by providing control forces on a long moment arm in the direction of desired response.

Vertical tail: The single vertical tail arrangement is adapted from Shuttle. A split rudder provides directional stability augmentation in the supersonic flight regime and drag modulation for the subsonic flight phases, approach and landing.

Interior arrangement: The arrangement of the LH_2 and LO_2 tanks and payload compartment provides a fuselage packaging efficiency of 0.734 excluding propulsion and crew compartment. This is achieved in part by the use of multicell tanks, in part by the use of a hybrid integral tank structure and in part by the integration of the LO_2 tank with the wing carry through, and the adjacent location of the payload compartment. As shown in figure 2-2, the large LH_2 tank is of 3-cell construction; both the LO_2 tank and payload compartments utilize 5 cells. The payload compartment is located close to the vehicle center of gravity to minimize the effects of payload variations on c.g. and trim.

Propulsion: The BGT boost propulsion employs 12 main engines which are derived from the Shuttle orbiter main engines. Two small space tug-type engines are employed during the post-ascent period for control augmentation and range extension. Four integral hydrogen-burning airbreathers are used for idle-mode descent, final approach and landing. Sufficient fuel is carried to provide a 173 s. mi. loiter capability at the end of the mission to accommodate delays in landing or to permit the use of alternate fields. Through the modular addition of nacelle-mounted airbreathers, a self-ferry capability also is provided.

Configuration data: Selected data which summarize the geometrical characteristics of the baseline BGT are presented in Table 2-IX.

Aerodynamic characteristics.- Aerodynamic characteristics of the baseline BGT are based on a reference wing area of 1115 m^2 (12 000 ft^2). This is the planform area of the basic wing including that portion covered by the fuselage and excluding the forward delta.

For maximum range, the BGT will glide at maximum lift-drag ratio. Key summary hypersonic aerodynamic characteristics are:

$$C_{D_o} = 0.0149$$

$$C_{D_i}/C_L{}^2 = 1.62$$

$$\alpha = 10°$$

$$C_L = 0.133$$

$$C_D = 0.0436$$

$$L/D = 3.0$$

Reference wing loading at landing is 277 600 kg/1115 m^2 or 249 kg/m^2 (51 lb/ft^2). Landing speed is approximately 267 km/hr (166 s. mi./hr.).

Mass properties summary. Estimated weights of the baseline BGT are summarized in Table 2-X. The weight estimates summarized in the table are the basis for derivation of the weight fractions for use in Module 3 and weight parameters for Module 4.

The primary structural and subsystems weights for the boost-glide transport (BGT) are estimated to be representative for the 1990-2000 time period. In predicting BGT weights using the current Space Shuttle Orbiter weight statement as a reference, selected weight improvements associated with this later time period are incorporated.

A major reduction in the unit weights of the primary structure relative to Shuttle conventional materials and design is potentially achievable with advance materials and composites. Therefore, the BGT unit weights for the wing, tail, moveable surfaces and body, including carry-through and thrust structure, are predicted as 25 per cent less than Shuttle Orbiter unit weights.

TABLE 2-IX.- BGT CONFIGURATION DATA

	SI units	English units
Body		
Length	91.4 m	300 ft
Half-width	9.14 m	30 ft
Height	8.11 m	26.6 ft
LH_2 tank volume	11 180 m^3	120 300 ft^3
LO_2 tank volume	3920 m^3	42 170 ft^3
Payload compartment volume	1800 m^3	19 400 ft^3
Fuselage total volume	7015 m^3	247 700 ft^3
Wing		
Reference area	1115 m^2	12 000 ft^2
Exposed area less fwd delta	537 m^2	5780 ft^2
Exposed area with fwd delta	610 m^2	6565 ft^2
Aspect ratio	2.265	
Taper ratio	0.20	
Root chord	36.97 m	121.3 ft
Tip chord	7.41 m	24.3 ft
Exposed root chord	26.21 m	86.0 ft
Mean aerodynamic chord	22.19 m	72.8 ft
Wing span	50.23 m	164.8 ft
Exposed structural semi-span	15.97 m	52.4 ft
Leading edge sweep	48.5°	
Trailing edge sweep	-5°	
Elevon hinge line sweep	0°	
Elevon area	108.7 m^2	1170 ft^2
Vertical tail		
Area	121.8 m^2	1311 ft^2
Root chord	13.11 m	43.0 ft
Tip chord	5.94 m	19.5 ft
Span	14.63 m	48.0 ft
Leading edge sweep	45°	
Rudder area	30.6 m^2	329 ft^2
Canard (all movable)		
Exposed area	33.4 m^2	360 ft^2

TABLE 2-X.- BGT WEIGHT SUMMARY

Item	Weight kg	Weight lb
Structure, W_S	(114 010)	(251 340)
Wing	16 440	36 240
Vertical tail	3 540	7 810
Canard	1 570	3 460
Body	50 250	110 780
Propellant tanks	38 810	85 550
Propellant tank insulation	3 400	7 500
Equipment, W_{Eq}	(33 950)	(74 840)
Post-ascent engine and system	500	1 100
Propellant system	10 680	23 540
Landing gear	9 150	20 160
Surface controls	2 350	5 170
Power and distribution	7 300	16 100
Hydraulics	2 940	6 480
Environmental control	1 030	2 260
Thermal protection system, W_{TPS}	(23 670)	(52 190)
Wing	8 930	19 680
Vertical tail	1 510	3 330
Body	13 230	29 180
Main engine and accessories, W_{ME}	(35 730)	(78 760)
Air-breathing propulsion system, W_{TJ}	(12 070)	(26 600)
Avionics	(1 860)	(4 100)
Payload provisions	(4 580)	(10 100)
Growth/uncertainty	(17 730)	(39 100)
DRY WEIGHT	(243 600)	(537 000)
Personnel	(630)	(1 400)
Payload	(19 050)	(42 000)
ABPS fuel	(7 620)	(16 800)
Residuals	(6 710)	(14 800)
LANDING WEIGHT	(277 610)	(612 000)

TABLE 2-X.- BGT WEIGHT SUMMARY - Concluded

Item	Weight	
	kg	lb
Post-ascent propulsion and supplementary ACS propellants	(7 710)	(17 000)
Glide-phase losses	(1 810)	(4 000)
BEGIN-GLIDE WEIGHT	(287 130)	(633 000)
Reserve fluids	(5 220)	(11 500)
Ascent-phase losses	(6 580)	(14 500)
Useful main engine propellants	(1 515 470)	(3 341 000)
GROSS LIFT-OFF WEIGHT	(1 814 400)	(4 000 000)

The unit weights for the BGT propellant tanks and for the thermal protection system are also developed from current Shuttle estimates. Weight reductions are not projected for these elements in this baseline, however.

Bases for weight estimates for major structural elements are reviewed in conjunction with structural design summary descriptions in the following sections.

Residual propellant weight estimates are based on projected reductions in both gaseous and liquid residuals. Through the use of heat exchangers to warm pressurant gases in conjunction with sequential emptying of the multicell tanks, the gaseous hydrogen and oxygen residuals are estimated to be reduced to about 2860 kg (6300 lb). Through the employment of low-thrust post-ascent propulsion, liquid residuals are estimated to be reduced to 3850 kg (8500 lb) for a total of 6710 kg (14 800 lb) of residuals.

The 7710 kg (17 000 lb) of propellants for post-ascent propulsion represent 0.5 per cent of the total rocket engine propellants. These propellants otherwise would have been residuals in the multicell tanks, feed lines and in the main engines (about 30 per cent in the main engines alone).

Wing structure.- The primary structure of the wing, like the BGT airplane, is of aluminum alloy. The primary structure is protected from the external thermal environment by a reuseable surface insulation derived from that being developed for the Shuttle Orbiter.

The wing has a modified NASA XXXX-64 airfoil section. Thickness ratio of the basic wing (excluding the forward delta) increases from 8 per cent at the exposed root to 10 per cent at the tip chord. The torque box width is 50 per cent at the basic exposed root chord.

Skin and stringer covers, and web and truss spars make up the wing primary structure. The wing main spars and highly loaded ribs are built up of aluminum alloy machined caps which are riveted to corregated webs. The outer cover skins are stiffened with riveted hat sections. The skins are segmented for crack stoppage. Elevons are of two-piece aluminum construction employing honeycomb covers. Sealing of the elevon-wing gap prevents cross-flow.

Based on a correlation of torque box, leading and trailing edges, secondary structure and control surfaces, the unit weight of the BGT wing is estimated at 27.0 kg/m^2 (5.52 lb/ft^2) of exposed plan area.

Vertical tail structure.- The vertical tail consists of a fixed fin and split rudder/speed brake. At velocities above Mach 0.6 the split rudder's neutral position forms a 10° symmetrical wedge. Below Mach 0.6, the cross-section is a 60/40 double-wedge airfoil. The fin and rudder/speed brake panel elements are built up of aluminum skins over milled spars. The rudder is 25 per cent of the tail planform area. Unit weight of the vertical tail based on a plan area of 121.8 m^2 (1311 ft^2) is 29.1 kg/m^2 (5.97 lb/ft^2).

Canard surface.- The canard surfaces are all-moveable airfoils which are folded against the sides of the forebody during high-speed flight and are deployed subsonically. Like the elevons, the canard surfaces employ honeycomb covers and are of aluminum construction. A spider-like inner structure, including the close-out rib, in conjunction with the covers carries chordwise and spanwise loads to the hub. The two canard surfaces have an exposed area of 33.4 m^2 (360 ft^2) which is 3 per cent of the wing reference area. The estimated unit weight of 47.0 kg/m^2 (9.63 lb/ft^2) includes the weight of the hub, deployment mechanism and controls.

Body and tank structures.- The fuselage airframe is of aluminum alloy and is maintained below about 422 K (300°F) by reuseable surface insulation.

The major fuselage structure utilizes a hybrid integral tank design concept. This concept, illustrated in figure 2-4, was investigated during Shuttle phase B for the earlier Orbiter design which carried its main engine

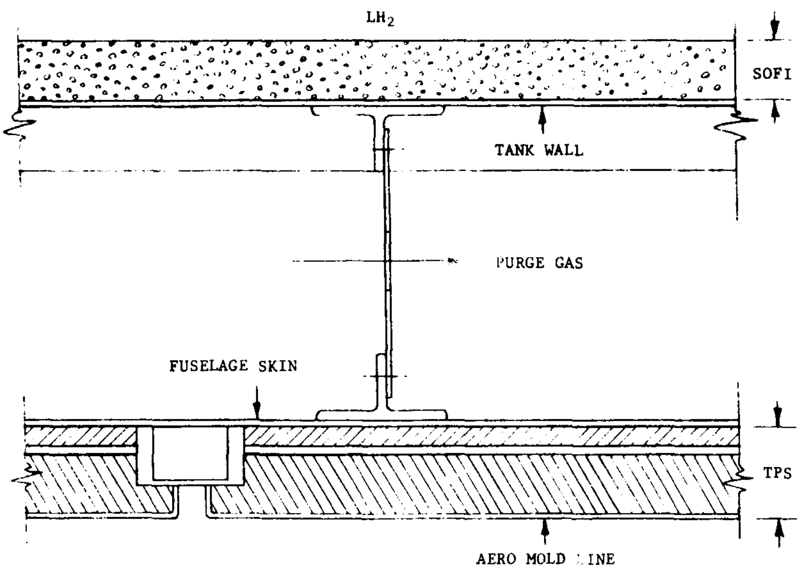


Figure 2-4.- Hybrid Integral Structure

propellants onboard. The structure is characterized as a hybrid because it retains the outer covers and pressure vessel membranes of a non-integral design but integrates them into a working unit through interconnecting frames. This design is utilized for the crew compartment, LH_2 tank, LO_2 tank and passenger compartment sections of the BGT fuselage.

Principal advantages for the hybrid integral tank relative to non-integral tank designs are:

- Improved fuselage volumetric efficiency
- Improved material strength
- Improved structural efficiency
- Reduced structural weight

Material strength improvements stem from the lower temperature of the fuselage structure which is integrated with the LH_2 and LO_2 tanks. At launch, the integral structure is precooled by the propellants. This pre-cooling results in lower in-flight structural temperatures for given heating loads.

A primary problem with hybrid integral propellant tanks is that posed by differential thermal contraction and expansion, particularly for the LH_2 tank portion. Thermal isolation of the structure from both the external and tank internal environments and the presence of heat paths within the structure are the primary means of alleviating this problem. Consequently, the BGT design requires effective insulation inside the LH_2 tank and improved insulating properties of the RSI. Additionally, flexure in the webs of frames can permit some longitudinal displacements.

The LO_2 tank is integral with the inside of the wing carry-through structure. The carry-through juncture with the outer wing is a bolt-on configuration in which the major loads are transferred through spar attachments. Main spar and spar-cap loads are carried through a series of stiff ring frames around the multicell LO_2 tank. Wing lower cover loads also are transferred into the lower body skin in a uniformly distributed manner by means of tension bolts. This avoids the weight penalty for redistributing the lower spar cap loads on both the fuselage and outer panel sides of the lugs. The upper caps in the wing carry-through frames serve a double purpose in also supporting the floor of the payload compartment. The frames are constrained by longitudinal tension ties which are required by the multicell tank. Shear webs which stabilize the frames also act as tank baffles.

The payload compartment is integral with the upper fuselage structure and is integrated with the LO_2 tank and carry-through. The width of the inner cells of the payload compartment is equal to those of the LO_2 tank, thus permitting use of continuous tension ties across both pressure vessels. Payload compartment doors are located on the sides with access over the wing, employing separate ground equipment.

The aft fuselage structurally supports the BGT propulsion systems (main, air-breathing and post-ascent), subsystem equipments (APU, environmental control, portions of the avionics, and launch umbilical), and the vertical tail. In order to provide access to internally-mounted equipment for quick turnaround, the aft external structure is lightly loaded consistent with the provision of large access panels. Main engine loads and vertical tail loads are transferred directly to thrust structure shelf beams. Distribution of thrust loads to the LO_2 tank and airframe is primarily from the shelves to longerons in the integral LO_2 tank/wing carry-through structure. The aft fuselage structure is basically of machined and built-up aluminum alloy construction. Inconel stresskin sandwich is employed for the base heat shield to withstand the severe thermal and acoustic environments.

The 50 250 kg (110 780 lb) estimated weight of the body, Table 2-X, is comprised of the elements in the following tabulation. The outer shell, crew compartment and thrust structure unit weights represent a postulated reduction of 25 per cent from Shuttle Orbiter values.

Outer shell	3215 m^2x10.55 kg/m^2 = 34 000 kg (34 600 ft^2) x (2.16 lb/ft^2) = (75 000 lb)
Crew compartment	79.0 m^2 x 22.6 kg/m^2 = 1780 kg (850 ft^2) x (4.63 lb/ft^2) = (3930 lb)
Payload compartment structure	549 m^3 x 5.61 kg/m^3 = 3085 kg (19 400 ft^3) x (0.35 lb/ft^3) = (6800 lb)
Payload compartment insulation	585 m^2 x 0.73 kg/m^2 = 426 kg (6297 ft^2) x (0.15 lb/ft^2) $\doteq$ (940 lb)
Carry-through	120 m^2 x 54.2 kg/m^2 = 6505 kg (1290 ft^2) x (11.1 lb/ft^2) = 14 340 lb)
Thrust structure	22 270 000 N x .000 199 kg/N = 4430 kg (5 008 000 lb) x (.00 195) = (9770 lb)

The main propellant tanks (fuel and oxidizer) are monocoque vessels designed by pressure requirements. Since the tension load is proportional to the pressure and radius, and the total weight is proportional to the surface area, the tank unit weights are a function of tank volume. Comparison of the BGT tanks with the external fuel tank for the Shuttle considers that the external fuel tanks are expendable while the tanks required for the BGT must be good for the life of the aircraft. Therefore, any advanced materials and resulting weight reductions will be offset by the more stringent requirements resulting from fatigue and long life criteria. BGT tank weight estimates are summarized below.

LH_2 tank structure	3407 m^3 x 8.96 kg/m^3 = 30 540 kg (120 300 ft^3) x (0.559 lb/ft^3) = (67 330 lb)
LO_2 tank structure	1194 m^3 x 6.92 kg/m^3 = 8270 kg (42 170 ft^3) x (0.432 lb/ft^3) = (18 220 lb)

Cryogenic tank insulation system weights are defined in the following tabulation. The insulation systems include multi-layer FEP Teflon-coated Kapton-H liner in all cryogenic tanks to minimize leakage of propellants into the insulation.

LH_2 tank insulation	1858 m^2 x 1.22 kg/m^2 = 2270 kg (20 000 ft^2) x (.25 lb/ft^2) = (5000 lb)
LO_2 tank insulation	929 m^2 x 1.22 kg/m^2 = 1135 kg (10 000 ft^2) x .25 lb/ft^2) = (2500 lb)

Thermal protection system.- The thermal protection system for the baseline BGT consists of: (1) ceramic reuseable surface insulation (ceramic panels with an external waterproof coating on a strain-isolation foam pad) directly bonded to the airframe in areas exposed to surface temperature between 617 K and 1644 K (650°F and 2500°F); (2) elastomeric reuseable surface insulation directly bonded to the airframe in areas exposed to temperatures below 617 K (650°F); and (3) reinforced carbon-carbon (RCC) material in the wing leading edge and body nose cap in areas exposed to temperatures above 1644 K (2500°F).

Ceramic RSI: Basic components of the ceramic RSI system are:

- Silica panels - Silica is projected for use in the ceramic panels of the BGT. Weight estimates for these panels are based on data regarding the advanced silica system proposed for the Shuttle Orbiter.

- Pad - An arrestor plate and pad provide strain isolation of the ceramic panels from the aluminum alloy structure and accommodate local surface irregularities.

- Coating - A waterproof silica coating provides thermal control optical characteristics, rain erosion protection and abrasion resistance for ground handling and atmospheric flight.

- Adhesive - A silicone elastomer adhesive system is used for both panel and pad bonding.

Panel-to-panel gaps avoid ceramic RSI panel compressive loads at maximum expansion. The gaps are partially filled with a low-density-quartz expandable gasket to thermally protect the substructure at the base of the joint.

Elastomeric RSI: The elastomeric RSI is a flexible, open-cell structural material possessing good low-temperature flexural properties, and is attached to the airframe in coated sheets with RTV-560 bond. The RSI is coated with an elastomeric silicon resin (for waterproofing) pigmented with titanium dioxide and carbon black (for thermal control). It is an impact-resistant, easily repairable material which will minimize susceptability to handling damage.

Figure 2-5 illustrates the cross-sectional configurations of the ceramic and elastomeric RSI's.

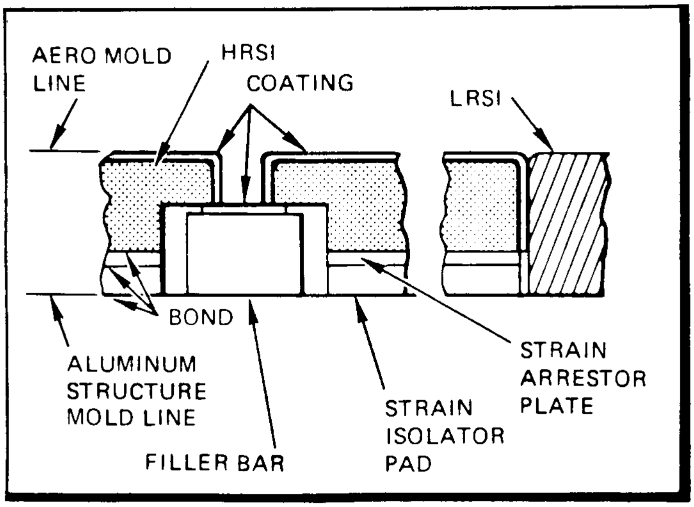


Figure 2-5.- Typical High and Low Temperature RSI

Reinforced carbon-carbon elements: RCC application to the body nose and wing leading edge sections of the BGT is also based on Shuttle. RCC leading edge elements are approximately .76 m (30 inches) long. Adjacent elements are downstream-lapped for spanwise expansion capability. The joints are designed for individual leading edge element removal for maintainability. High-temperature bulk insulation backs up the RCC material to protect the structure. A silicon carbide oxidation inhibitor covers 100 per cent of the RCC surface. The RCC vehicle body nose cap is similar to the leading edge in material details, construction, insulation, and attachment, as indicated in figure 2-6.

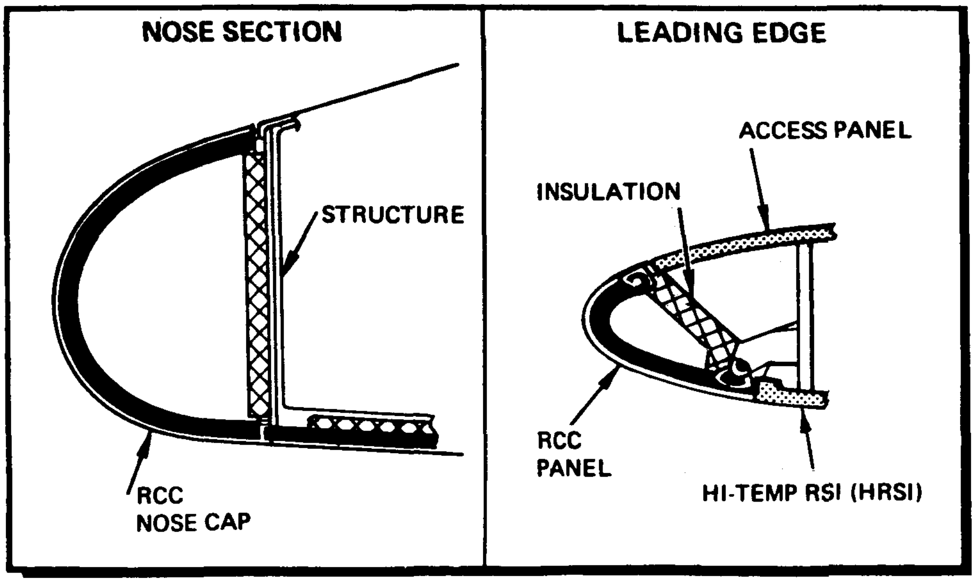


Figure 2-6.- Nose and Leading Edge TPS Configurations

The boost-glide descent phase of the BGT mission produces a less severe heat spike than the Shuttle Orbiter, but the BGT total heat input duration is considerably longer. Weight estimates for the thermal protection system are developed from Shuttle data utilizing a 2/3 power factor based on area to account for the thermal effects of distance downstream of stagnation conditions.

Main engine system.- The main engine system consists of twelve liquid propellant rocket engines which are derived from the Space Shuttle main engines. Engine improvements projected include: uprating of thrust, particularly at sea-level and low altitude boost conditions, improvement in specific impulse for all boost conditions, extension of engine operating life, and improvements in serviceability. The description in this module summarizes engine physical and performance characteristics. Operational characteristics and engine costs are included in Module 3.

Space Shuttle main engine reference: Each Space Shuttle engine operates nominally at a mixture ratio (LO_2/LH_2) of 6.0:1 and a chamber pressure of 20 680 000 N/m^2 (3000 psia) to produce a vacuum thrust of 2 091 000 N (470 000 lb) with a fixed nozzle area ratio of 77.5:1. Nominal vacuum specific impulse for a single engine operating under these conditions is 4463 N-sec/kg (455.2 lb_f- sec/lb_m). The installed specific impulse is reduced for Shuttle by about 0.2 per cent due to the cosine loss from the canted engine arrangement.

Thrust, specific impulse and mixture ratio for a single Shuttle main engine for alternate operating conditions are presented in Table 2-XI. Power level is continuously variable between the maximum and emergency power levels. The emergency power level is 109 per cent of the normal power level. Early in 1973, the main engine emergency power level was adopted as routine for the early boost period of Shuttle maximum payload missions. This power level is now to be supplied at no decrement to engine life.

The engine gimballing capability permits angular movement of the thrust chamber centerline ±9.0 deg (including 0.5 deg for overtravel and 0.5 deg for engine misalignment) from the static centerline.

Main engine derivatives for baseline BGT: For the time period of the 1990's, the following performance improvements are projected for derivatives of the Space Shuttle main engine.

- An emergency power level of 115 per cent nominal, providing a sea-level thrust of 1 918 200 N (431 250 lb). This is achieved primarily by allowing the fuel as well as the oxidizer main turbine inlet temperature to increase to 1170 K (1650°F) at EPL.

- Increase in nominal vacuum specific impulse to 4560 N-sec/kg (465 lb_f-sec/lb_m), an improvement of about 2 per cent.

Routine operation at the 109 per cent level during early boost reduces the number of engines required, and provides a 2 per cent improvement in specific impulse at sea-level. The availability of a 115 per cent power level provides added margin for an engine-out condition.

TABLE 2-XI.- SPACE SHUTTLE MAIN ENGINE OPERATING CONDITIONS

Engine characteristic	Sea-level		Vacuum	
	SI units	English units	SI units	English units
Emergency power level				
Thrust	1 856 000 N	417 300 lb	2 279 000 N	512 300 lb
Specific impulse (nom.)	3636 $\frac{\text{N-sec}}{\text{kg}}$	370.8 sec	4465 $\frac{\text{N-sec}}{\text{kg}}$	455.3 $\frac{\text{lb}_f\text{-sec}}{\text{lb}_m}$
Mixture ratio	6.0	6.0	6.0	6.0
Normal power level				
Thrust	1 668 000 N	375 000 lb	2 091 000 N	470 000 lb
Specific impulse (nom.)	3562 $\frac{\text{N-sec}}{\text{kg}}$	363.2 sec	4464 $\frac{\text{N-sec}}{\text{kg}}$	455.2 $\frac{\text{lb}_f\text{-sec}}{\text{lb}_m}$
Mixture ratio range	5.5 to 6.5	5.5 to 6.5	5.5 to 6.5	5.5 to 6.5
Minimum power level				
Thrust	-	-	1 045 000 N	235 000 lb
Specific impulse (nom.)	-	-	4446 $\frac{\text{N-sec}}{\text{kg}}$	453.4 $\frac{\text{lb}_f\text{-sec}}{\text{lb}_m}$
Mixture ratio range	-	-	5.5 to 6.5	5.5 to 6.5

Engine weights of a single main engine for Shuttle are listed in the following tabulation. The weights do not include the gimbal system or heat shield.

Conditions	Dry		Wet	
	kg	lb	kg	lb
Prestart	2874	6335	3072	6773
Operating	-	-	3100	6834
Burnout	-	-	3072	6773

Figure 2-7 shows the static envelope for a Shuttle main engine.

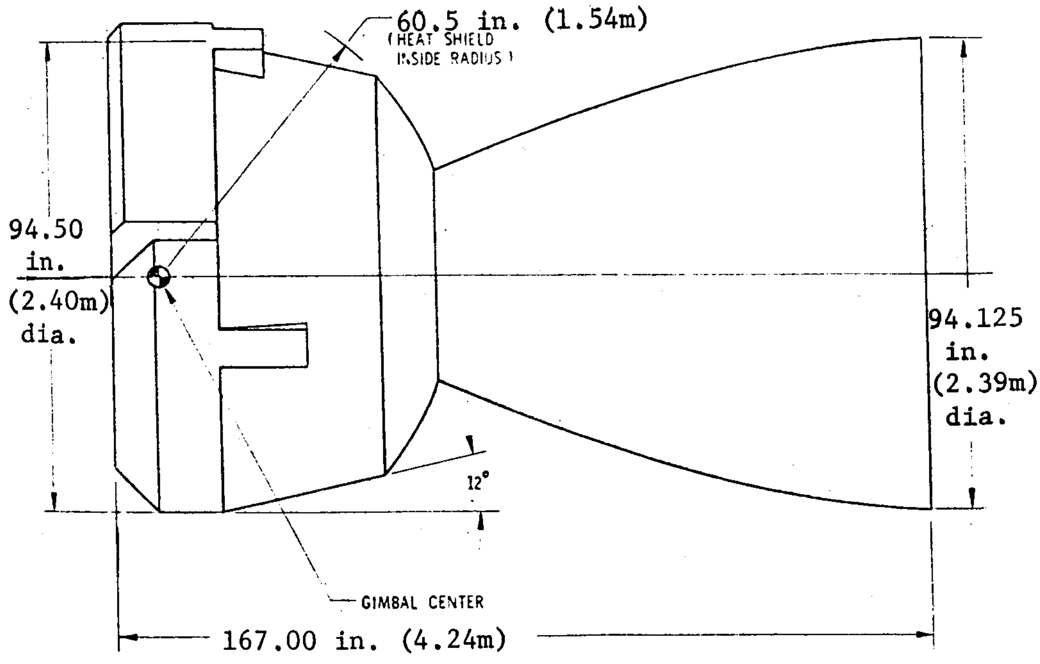


Figure 2-7.- Static Envelope Space Shuttle Main Engine

Achievement of the 2 per cent increase in vacuum specific impulse is expected to require the more substantial engine advancement and changes in engine geometry, including an increased expansion ratio and possibly variable nozzle geometry for those engines which operate for longest duration at the higher boost altitudes.

Figure 2-3 shows the nozzle end-profiles for installation of 12 main engines in conjunction with the post-boost and air-breathing engines in the baseline BGT. Six fixed-geometry, fixed-position engines are located in the outboard portion of the installation. As propellant is consumed during boost, these engines are shut-down first as required to limit maximum acceleration to 2g. Sequential shut-down from the extreme outboard engines progressively inboard minimizes total cosine losses.

Six main engines are of variable geometry and are fully gimbaled. These engines are clustered to minimize the overall clearance envelope required for control deflections. (Counter-deflection of adjacent engines is not required.) Installation within the limited base area is made possible by: (1) outboard positioning of the fixed engines including an external fairing at the wing root; (2) superimposing the nozzle deflection envelope behind the air-breathers which are inoperative during boost; and (3) employment of a lower aft body flap as in the Shuttle to control aerodynamically-induced moments on the gimbaled engines. At termination of the boost phase, the gimbaled engines return to their null positions so as to avoid interference with the air-breathers and the post-boost propulsion system.

Air-breathing propulsion system.- The primary purpose of the air-breathing propulsion system (ABPS) is to provide loiter flight capability upon completion of the glide phase of each mission. The ABPS also provides self-ferry capability from alternate landing sites to the launch sites through the employment of add-on engines.

The integral ABPS, which is available for all missions, utilizes four hydrogen-burning turbojet engines installed within the aft end of the fuselage. The subsonic air induction system employs swing-out scoop-type inlets which are fully closed and thermally protected during the high-speed regimes. Liquid hydrogen fuel for the ABPS is carried in the aft compartment of the main LH_2 tank's center cell.

The ferry system consists of the integral ABPS plus four additional engine modules. The latter are required to provide the greater thrust and margin for horizontal take-off. The add-on engines are pod-mounted to minimize weight and design impact on the BGT and to facilitate field installation. Fuel for ferry missions is carried in the center cell of the main LH_2 tank.

The turbojet engine selected for the baseline BGT is a scaled version of a hydrogen-burning design studied by P&W for potential application to the Space Shuttle. The engine studied for Shuttle is designated JTF22A-4(H), and is described by Pratt and Whitney as follows:

"The JTF22A-4(H) is a hydrogen-fueled, nonaugmented derivative of the F401-PW-400 turbofan engine. . . It is an axial flow, two-spool turbofan engine with a fixed-area exhaust nozzle. At sea-level static this engine has a 0.71 bypass ratio and an overall compression ratio of 28.5:1.

The basic F401-PW-400 engine, designed for the F-14B aircraft, has structural and mechanical design features that include modular construction, low weight, and structural integrity for high maneuver loads, as well as high component efficiencies in both the transonic and subsonic operating regimes. The engine design includes variable geometry in both the fan and compressors for improved performance and inlet distortion tolerance and an annular ram induction combustor for optimum combustion efficiency. Modular construction of the engine provides for field installation of prebalanced components to minimize engine maintenance time.

The low rotor consists of a three-stage fan and one low compressor stage driven by a two-stage turbine through concentric shafting. The 10-stage high pressure compressor is driven by a 2-stage, air-cooled turbine . . . The full annular fan duct surrounds the gas generator and supplies fan bypass air to the exhaust nozzle.

The engine is based on NASA ground rules that specify "minimum modification" to adapt the F401 engine to match space shuttle requirements and to operate on hydrogen fuel. The fan, compressor, and turbine assemblies are the same as the F401-PW-400. The F401 augmentor and variable area nozzle are replaced by a fixed area nozzle. A hydrogen vaporizer is installed in the nozzle exhaust cone . . . Variable geometry actuation systems that are powered by JP fuel on the F401 are revised to operate on compressor discharge air. Fuel injectors, fuel manifolds, and combustor air distribution are modified to accommodate use of hydrogen fuel."

Figure 2-8 shows the general configuration of the JTF22A-4(H) engine.

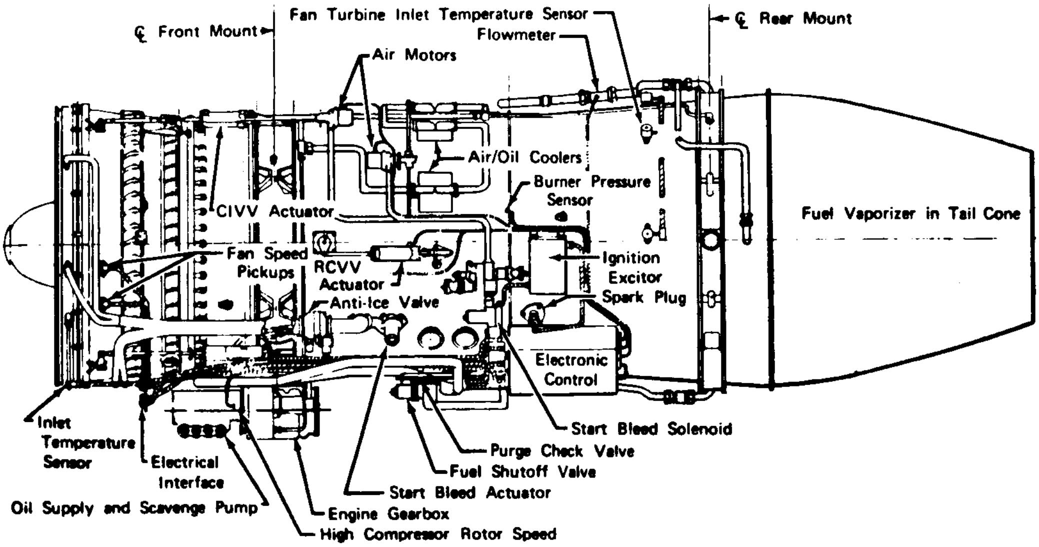


Figure 2-8.- JTF22A-4(H) Engine (Left Side)

Estimated characteristics of a scaled version of this engine for application to the BGT are:

Thrust at M = 0.6 loiter	133 400 N	(30 000 lb)
Sfc at M = 0.6 loiter	0.0334 $\frac{kg}{N\text{-}hr}$	(0.33 $\frac{lb_m}{lb_f\text{-}hr}$)
Sea-level static thrust	200 200 N	(45 000 lb)
Engine specific thrust, T_{SL}/W_{TJ}	103 N/kg	(10.5)
Engine weight	1940 kg	(4280 lb)
Engine installed weight	2750 kg	(6070 lb)
Inlet diameter	1.52 m	(60 in)
Maximum diameter	1.63 m	(64 in)
Engine length	4.85 m	(191 in)

ABPS LH_2 fuel requirements are based on the following:

Loiter range	278 km	(173 s. mi.)
Loiter velocity	710 $\frac{km}{hr}$	(441 s. mi./hr)
Loiter duration	0.391 hr	
BGT loiter weight, avg	274 000 kg	(604 000 lb)
Loiter L/D	≈5.0	
Loiter thrust, total	533 800 N	(120 000 lb)
Loiter sfc	0.0334 $\frac{kg}{N\text{-}hr}$	(0.33 $\frac{lb_m}{lb_f\text{-}hr}$)
Loiter fuel = thrust x sfc x duration	7080 kg	(15 600 lb)
Engine start, idle descent, taxi and shut-down fuel	540 kg	(1200 lb)
ABPS total fuel	7620 kg	(16 800 lb)

Use of an estimated subsonic L/D of 5.0 is a basic conservatism in the analysis. (Shuttle maximum L/D subsonically is 5.32.)

Post-ascent propulsion and control engine system- Two advanced state-of-the-art, high-performance LO_2/LH_2 engines are utilized to derive propulsive energy from propellants which otherwise would have been residuals. As described earlier, the engine system also augments aerodynamic controls during the early portion of the glide when dynamic pressures are low. The engine is derived from that defined for use in the Space Tug Point Design Study.

Space Tug reference engine: The reference engine has a nomonal vacuum specific impulse of 4609 N-sec/kg (470 $(lb_f\text{-sec})/lb_m$) and a thrust rating of 44 480 N (10 000 lb). A staged-combustion cycle with two preburners in conjunction with coaxial injectors and a nozzle area expansion ratio of 400 is used to achieve high engine efficiencies. Like the Shuttle main engines, the post-boost engines have a mixture ratio range from 5.5 to 6.5 with a nominal ratio of 6.0. The engine is equipped with boost pumps for both propellants which allow net positive suction heads of 15 feet for LH_2 and 2 feet for LO_2 without penalty to the main pumps.

The reference engine is capable of operating at relatively low thrust levels as shown in the following tabulation. Proportional throttling or step throttling between the full-thrust and pumped-idle modes has not been a requirement for this engine.

Operating mode	Thrust		I_{SP}	
	N	lb	N-sec/kg	$(lb_f\text{-sec})/lb_m$
Full thrust	44 480	10 000	4609	470
Pumped idle	4448	1000	4511	460
Pressure fed idle	156-187	35-42	3990-4334	407-442

Pitch and yaw deflections are by means of electromechanical servoactuators. The reference engine has a square gimbal pattern with gimbal angles of ±7 deg.

BGT post-boost engine system: Primary modifications to the reference engine concept for application to the BGT are: (1) increase in gimbal angles, (2) reduction of nozzle expansion ratio with attendant reduction in performance, and (3) incorporation of throttling capability.

In the post-boost period, the development of significant control forces through engine thrust vector control requires gimbal angles in the order of ±20 degrees as compared with ±7 degrees for the reference engine. Physical constraints in the engine installation, figure 2-3, indicate that the higher gimbal angles are attainable in the baseline BGT with a smaller nozzle. Therefore, for the baseline the nozzle expansion ratio is reduced to 200. This permits reduction of exit diameter to 0.76 m (30 in) and engine length to about 1.27 M (50 in.). Engine geometry is shown in figure 2-9.

Engine performance is estimated to be reduced about one percent by this change. Resulting values at full thrust for vacuum conditions are:

Thrust = 44 040 N (9900 lb)

Specific impulse = 4563 N-sec/kg $\left(465 \dfrac{lb_f\text{-sec}}{lb_m}\right)$

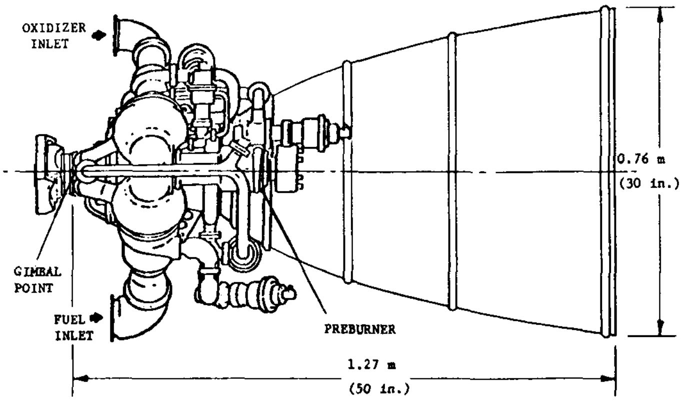


Figure 2-9.- Post-Ascent Engine Configuration

Proportional throttling to 50 per cent of the full thrust value is also incorporated for BGT baseline usage in order to meet both the thrust level and duration needs for control augmentation in the period of low dynamic pressure. The primary impact is on the engine control system.

Estimated weights for the post-boost engine system are listed below:

	Kg	Lb
Engines (2)	270	596
Gimbal actuation systems (2)	47	104
Propellant system increment	182	400
Total	499	1100

Propellant system.- The propellant system is comprised of a fill and drain subsystem, pressurization subsystem, vent subsystem, pre-valves, feed systems, instrumentation and propellant management, and supports and installation. The system is derived from the Shuttle Orbiter propellant system. Major differences are: (1) extension of capacity to feed 12 main engines, (2) deletion of External Tank, (3) modifications to accelerate operational turnaround, and (4) incorporation of a propellant utilization system in the BGT. The weight estimate for the BGT propellant system, 10 680 kg (23 540 lb), is scaled from Shuttle on the basis of total engine thrust.

Landing gear.- The baseline BGT utilizes a conventional multi-wheel, aircraft-type landing system. As shown previously in figure 2-3, the main gear is supported by the forward wing spar and is retracted into the glove. Operation is forward retract/free fall. Gear actuation, steering and brakes are powered hydraulically. Landing gear weight is estimated at 0.033 times the 277 600 kg landing weight, or 9150 kg (20 160 lb).

Surface controls.- The surface control system provides the mechanisms and actuators to operate the aerodynamic surfaces in response to inputs from the flight control system. Two dual tandem actuators are utilized for each surface, i.e., each side of the split rudder and each of the two adjacent elevons on each wing panel. Estimated weights are 1890 kg (4160 lb) for elevon controls and 460 kg (1010 lb) for right and left rudder controls.

Power and distribution. - Electrical power is supplied by APU-driven 20/30 kva, 400 Hz generators during ascent and glide and as a landing back-up. During loiter and landing, electrical and hydraulic power are nominally derived from ABPS integrated drive generators and engine driven pumps. The estimated weight of power generation equipment, ratioed from Shuttle based on engine thrust, is 3080 kg (6800 lb). Estimated power conversion and distribution weight, ratioed from Shuttle based on landing weight, is 4220 kg (9300 lb).

Hydraulics.- The hydraulic subsystem provides power for operation of main engine thrust vector control, aerodynamic surface control, landing gear and other utility functions. Independent hydraulic systems are powered by variable displacement pumps driven by separate APU's. Nominal operating pressure of the hydraulic systems is 20 700 N/m^2 (3000 psi). The BGT hydraulic system weight estimate, Table 2-X, is derived from Shuttle and is related to landing weight.

Environmental control- The environmental control system consists of atmospheric control and thermal control subsystems. The atmospheric control provides chemical, humidity, temperature and pressure control of the crew and payload compartments. The thermal control subsystem provides active thermal control of avionics and mechanical equipment, and dissipates heat from the crew and payload compartments. The system weight estimate, Table 2-X, is increased from Shuttle Orbiter values to accommodate the increased load for the payload compartment.

Avionics.- The avionics system consists of guidance, navigation and control, data processing and software, communications, instrumentation, and displays and controls. Weights relative to Shuttle Orbiter avionics are reduced by deletion of equipment for in-space rendezvous and docking, Orbiter payload ommunications and management, manipulator operations and TV links with the ground. The Orbiter concept of minimum ground dependency is further extended in the ground checkout equipment onboard the BGT. These differences are reflected in the estimated avionics weight of 1860 kg (4100 lb) for the BGT.

Payload provisions.- Payload provision weights, Table 2-X, are reduced for the BGT relative to the HST baseline described in reference 1. In a passenger version, the short flight time and acceleration environment precludes on-board meal service. (Instead, beverage service could be provided the passengers in a pre-boarding area.) Figure 2-3 shows a partial view of a 200-seat arrangement. Provisions for luggage and limited cargo storage are located in the forward end of the compartment; utilities are located aft. The seats, which are the major payload provisions, will incorporate improved occupant restraints and seat attitude adjustments to accommodate the axial acceleration range of +2.0g to -0.033g as well as normal load factors.

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2. Eggers, A. J., Allen, H. J., and Neice, S. E.: A Comparative Analysis of the Performance of Long-Range Hypervelocity Vehicles, NACA TR 1382, 1958.

METHOD MODULE 3

DOC FORMULAS AND DRIVERS

METHOD MODULE 3 - DOC FORMULAS AND DRIVERS

Logic

This method module presents the procedures and the equations for calculating direct operating cost (DOC) for the BGT as a function of Driver Parameters and the change in the DOC which would result from improvements in the values of the Driver Parameters. By definition, the Driver Parameters are parameters with a significant impact on DOC and which are directly relatable to hypersonic technology. The DOC formulas have been organized to express the Driver Parameters in normalized form (e.g., W_{AF}/GLOW, airframe weight fraction) or other forms which are convenient for the purposes of the overall method. The DOC values are calculated using the DOC formulas and are expressed in the form of cents per ton-statute mile.

The changes in the DOC which result from projected improvements in the Drivers are calculated using equations expressed in the ratio (ΔDOC/DOC)/(ΔDriver/Driver). The ratios (ΔDOC/DOC)/(ΔDriver/Driver) are called "Driver Partials" herein for convenience. The logic sequence for this method module is illustrated in figure 3-1.

A demonstration section is included in which the procedures presented here are illustrated for the baseline BGT aircraft defined in Module 2, Baseline BGT Definition. In addition, a sensitivity analysis is included which indicates variations in the values of the Driver Partials, (ΔDOC/DOC)/(ΔDriver/Driver), which would result from uncertainties in parameters other than Drivers which are treated as constants in the DOC formulas. The "sensitivity parameters" include operational and cost factors which are a matter of judgment or independent estimate such as aircraft utilization, load factor, or the purchase price of fuel.

DOC formulas.- The DOC formulas are organized in the manner indicated in figure 3-2. A separate formula exists for each DOC element, fuel, crew, insurance, etc. These are then summed to give DOC total identified as DOC_{BL} ($DOC_{Baseline}$). The individual DOC formulas are given in Table 3-I. Derivation of the DOC formulas is presented in Appendix 3-A. The input and output values of all cost values in the formulas are in dollars, so that the calculated DOC values are in dollars per ton-statute mile. The formulas are expressed with coefficients in SI units so that inputs to the formulas must be in SI units.

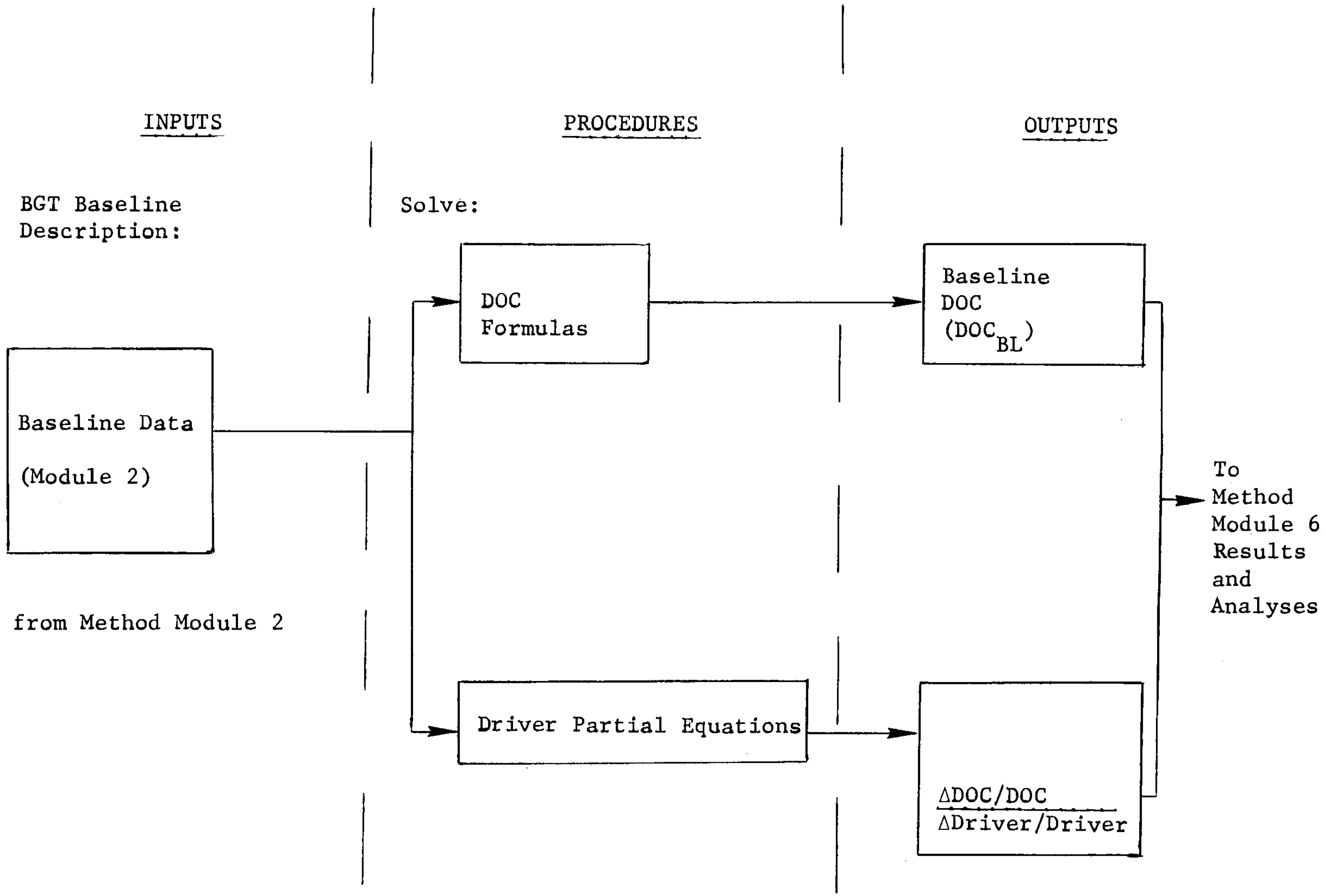

Figure 3-1.- Logic Sequence for Method Module 3

DOC Formulas

$\boxed{\begin{array}{l}DOC_{BL}\\ \text{Total}\end{array}} = \boxed{\begin{array}{l}DOC_{P}\\ \text{Propellant}\end{array}} + \boxed{\begin{array}{l}DOC_{C}\\ \text{Crew}\end{array}} + \boxed{\begin{array}{l}DOC_{I}\\ \text{Insurance}\end{array}} + \boxed{\begin{array}{l}DOC_{D}\\ \text{Depreciation}\end{array}} + \boxed{\begin{array}{l}DOC_{M}\\ \text{Maintenance}\end{array}}$

DOC_M =

$\boxed{DOC_{M/AF/L}\text{, Airframe* Maintenance Labor}}$

$+ \boxed{DOC_{M/AF/M}\text{, Airframe* Maintenance Material}}$

$+ \boxed{DOC_{M/ME}\text{, Main Engine Maintenance}}$

$+ \boxed{DOC_{M/TPS}\text{, Thermal Protection System Maintenance}}$

$+ \boxed{DOC_{M/TJ}\text{, Turbojet Engine Maintenance}}$

*Airframe (AF) as used here includes structure and all subsystems except main engines, turbojet engines, and thermal protection system.

Figure 3-2.- DOC Formula Summary

TABLE 3-I.- DOC FORMULAS

(Note: All inputs are in SI units)

$$DOC_P = \frac{1464\left[\left(\frac{C_H + C_O(MR)}{(MR) + 1}\right)\frac{W_{P_T}}{GLOW}\right]}{(LF)\ (W_{PL}/GLOW)\ R_T} \quad \text{\$/ton-statute mile}$$

$$DOC_C = \frac{(1.066 \times 10^6/GLOW)\ (t_F)}{(LF)\ (W_{PL}/GLOW)\ R_T} \quad \text{\$/ton-statute mile}$$

$$DOC_I = \frac{1464\ IR\ (C_{BGT}/GLOW)\ t_F}{(LF)\ (W_{PL}/GLOW)\ R_T\ U} \quad \text{\$/ton-statute mile}$$

$$DOC_D = \frac{321\ t_F\left[3.67(C_{BGT}/GLOW) + (C_{ME}/GLOW)\right]}{(LF)\ (W_{PL}/GLOW)\ R_T\ U\ L_d} \quad \text{\$/ton-statute mile}$$

$$DOC_{M/AF/L} = \frac{(0.04 + 0.048\ t_F)\left[0.01\left(\frac{W_S}{GLOW}\right) + 0.09\left(\frac{W_{Eq}}{GLOW} + \frac{W_{AV}}{GLOW}\right) + \frac{2720}{GLOW}\right] r_L}{(LF)\ (W_{PL}/GLOW)\ R_T^{1/2}\ t_F^{1/2}}$$

\$/ton-statute mile

$$DOC_{M/AF/M} = \frac{(9.07\ t_F + 9.15)\ (C_S/GLOW + C_{Eq}/GLOW + C_{AV}/GLOW)}{(LF)\ (W_{PL}/GLOW)\ R_T \times 10^3}$$

\$/ton-statute mile

TABLE 3-I.- DOC FORMULAS - Concluded

(Note: All inputs are in SI units)

$$DOC_{M/ME} = \frac{1.01 \left[\left(R_{OH}/F_{OH}\ C_{ME}/GLOW \right) + \left(11\ r_L + 83 \right)\ N_{ME}/GLOW \right] T_{ME}^{\ 1/2}}{(LF)\ (W_{PL}/GLOW)\ R_T}$$

\$/ton-statute mile

$$DOC_{M/TPS} = \frac{1464\ C_{TPS}/GLOW}{LF\ (W_{PL}/GLOW)\ R_T} \left(K_{TPS} + \frac{1}{L_{TPS}} \right) \quad \text{\$/ton-statute mile}$$

$$DOC_{M/TJ} = \frac{0.051\ C_{TJ}/GLOW + \left(1317 + .013\ T_{TJ} \right)\ N_{TJ}\ r_L/GLOW}{(LF)(W_{PL}/GLOW)\ R_T}$$

\$/ton-statute mile

Terms are defined in Tables 3-III and 3-IV.

Driver definitions.- Driver Parameters have been identified as parameters which enter into the calculation of DOC, significantly impact its value, and are directly relatable to technology.

The following terms have been identified as Driver Parameters:

Airframe weight fraction - $W_{AF}/GLOW$

Thermal protection system life - L_{TPS}

Thermal protection system average weight per unit area - $(W/A)_{TPS}$

Weight to thrust ratio for main engine - $(W/T)_{ME}$

Lift-to-drag ratio (hypersonic) - L/D

Specific impulse (vacuum) - I_{SP}

In most of the DOC formulas, the Driver Parameters are contained in two terms:

$W_{P_T}/GLOW$ and $W_{PL}/GLOW$

The equation for $W_{P_T}/GLOW$ (propellant fraction) is:

$$\left(\frac{W_{P_T}}{GLOW}\right) = \frac{1}{K_P}\left(1 - \frac{1}{e^A}\right)$$

$$\text{where } A = \left\{\frac{1}{I_{SP}}\left(808.67\left[1 - \frac{1}{e^B}\right]^{1/2} + 160.28 - 33.03 \sin \phi \cos \theta\right)\right\}$$

$$\text{and } B = \left\{\frac{R_T}{1082\ (L/D)\left(1 + \frac{0.2}{L/D}\right)}\right\}$$

The Drivers L/D and I_{SP} both appear in this expression.

The payload weight fraction is written as:

$$\frac{W_{PL}}{GLOW} = 1 - \frac{W_{AF}}{GLOW} - \frac{W_{ME}}{GLOW} - \frac{W_{TPS}}{GLOW} - \frac{W_{TJ}}{GLOW} - \frac{W_{P_T}}{GLOW} - \frac{W_{Misc}}{GLOW} - \frac{W_{AV}}{GLOW}$$

The first term $W_{AF}/GLOW$ is the airframe weight fraction which is a Driver Parameter.

The second term can be written as:

$$\frac{W_{ME}}{GLOW} = (W/T)_{ME}\ (T/W)_{GLOW}$$

where,

$(W/T)_{ME}$ is the Driver Parameter.

The third term can be written as:

$$\frac{W_{TPS}}{GLOW} = (W/A)_{TPS}\ A_{TPS}/GLOW$$

where,

$(W/A)_{TPS}$ is the Driver Parameter

The final Driver Parameter, L_{TPS}, (thermal protection system life) is contained directly in the DOC maintenance formula for the TPS, $DOC_{M/TPS}$.

Driver Partial Equations.- The driver partial equations $(\Delta DOC/DOC)/(\Delta Driver/Driver)$ are presented in Table 3-II. Derivation of these equations is presented in Appendix 3-B. The driver partial equations are organized so that a separate value of $(\Delta DOC_i/DOC_i)/(\Delta Driver_j/Driver_j)$ is calculated for each DOC element, (i), (DOC_i = DOC_P, DOC_C, DOC_I, etc.), and for each Driver Parameter, (j), ($Driver_j$ = $W_{AF}/GLOW$, L_{TPS}, $(W/A)_{TPS}$, etc.)

"Total driver partials" which indicate the impacts on DOC total (called DOC_{BL}) of each Driver Parameter, (i), are then computed by the equation:

TABLE 3-II.- "DRIVER PARTIAL" EQUATIONS

(All terms are defined in TABLES 3-III and 3-IV)

For Driver $W_{AF}/GLOW$

$$\frac{\Delta DOC_i/DOC_i}{(\Delta W_{AF}/GLOW)/(W_{AF}/GLOW)} = \frac{W_{AF}/GLOW}{\frac{W_{PL}}{GLOW} - P_{W_{AF}}\left(\frac{W_{AF}}{GLOW}\right)}$$

where, $DOC_i = DOC_P, DOC_C, DOC_I, DOC_D, DOC_{M/AF/M}, DOC_{M/ME}, DOC_{M/TPS}, DOC_{M/TJ}$

$$P_{W_{AF}} = \frac{\Delta W_{AF}/GLOW}{W_{AF}/GLOW}$$

Use $P_{W_{AF}} = -0.1$

$$\frac{\Delta DOC_{M/AF/L}/DOC_{M/AF/L}}{(\Delta W_{AF}/GLOW)/(W_{AF}/GLOW)} = \frac{(1.08)\ \frac{W_{AF}}{GLOW}}{\frac{W_{PL}}{GLOW} - P_{W_{AF}}\left(\frac{W_{AF}}{GLOW}\right)}$$

TABLE 3-II.- "DRIVER PARTIAL" EQUATIONS - Continued

(All terms are defined in TABLES 3-III and 3-IV)

For Driver, L_{TPS}
$\dfrac{\Delta DOC_i/DOC_i}{\Delta L_{TPS}/L_{TPS}} = 0$ For DOC_i = DOC_P, DOC_C, DOC_I, DOC_D, $DOC_{M/AF/L}$, $DOC_{M/AF/M}$, DOC_{ME}, and $DOC_{M/TJ}$
$\dfrac{\Delta DOC_{M/TPS}/DOC_{M/TPS}}{\Delta L_{TPS}/L_{TPS}} = -\left[\dfrac{\dfrac{1}{L_{TPS}}}{K_{TPS} + \dfrac{1}{L_{TPS}}}\right]\left(\dfrac{1}{1 + P_{L_{TPS}}}\right)$ where, $P_{L_{TPS}} = \dfrac{\Delta L_{TPS}}{L_{TPS}}$ Use technology projection for $\dfrac{\Delta L_{TPS}}{L_{TPS}}$

TABLE 3-II.- "DRIVER PARTIAL" EQUATIONS - Continued

(All terms are defined in TABLES 3-III and 3-IV)

For Driver $(W/A)_{TPS}$

$$\frac{\Delta DOC_i/DOC_i}{\Delta(W/A)_{TPS}/(W/A)_{TPS}} = \frac{A_{TPS}\ (W/A)_{TPS}/GLOW}{\frac{W_{PL}}{GLOW} - P_{(W/A)_{TPS}}\ A_{TPS}\ (W/A)_{TPS}/GLOW}$$

where, DOC_i = all DOC elements (i.e., $DOC_i = DOC_P$, DOC_C, DOC_I, . . .)

$$P_{(W/A)_{TPS}} = \frac{\Delta(W/A)_{TPS}}{(W/A)_{TPS}}$$

Use $P_{(W/A)_{TPS}} = -0.1$

For Driver $(W/T)_{ME}$

$$\frac{\Delta DOC_i/DOC_i}{\Delta(W/T)_{ME}/(W/T)_{ME}} = \frac{(W/T)_{ME}\ (T/W)_{GLOW}}{\frac{W_{PL}}{GLOW} - P_{(W/T)_{ME}}\ (W/T)_{ME}\ (T/W)_{GLOW}}$$

where, DOC_i = all DOC elements

$$P_{(W/T)_{ME}} = \frac{\Delta(W/T)_{ME}}{(W/T)_{ME}}$$

Use $P_{(W/T)_{ME}} = -0.1$

TABLE 3-II.- "DRIVER PARTIAL" EQUATIONS - Continued

(All terms are defined in TABLES 3-III and 3-IV)

For Driver L/D
$$\frac{\Delta DOC_P/DOC_P}{\Delta(L/D)/(L/D)} = \frac{1}{P_{L/D}} \left[\frac{\dfrac{1464 \left\{ \left(\dfrac{C_H + C_O\,(MR)}{(MR) + 1} \right) \left(\dfrac{W_{P_T}}{GLOW} \right)' \right\}}{(LF) \quad (W_{PL}/GLOW)' \quad R_T}}{DOC_P} - 1 \right]$$ where, $P_{L/D} = \frac{\Delta L/D}{L/D}$ $$\left(\frac{W_{P_T}}{GLOW}\right)' = \frac{1}{K_P}\left(1 - \frac{1}{e^A}\right)$$ where $A = \left\{ \dfrac{1}{I_{SP}} \left(808.67 \left[1 - \dfrac{1}{e^B} \right]^{1/2} + 160.28 - 33.03 \sin \phi \cos \theta \right) \right\}$ and $B = \left\{ \dfrac{R_T}{1082 \left(1 + P_{L/D}\right)(L/D)\left[1 + \dfrac{0.2}{\left(1 + P_{L/D}\right)(L/D)}\right]} \right\}$ $$\left(\frac{W_{PL}}{GLOW}\right)' = \frac{W_{PL}}{GLOW} + \frac{W_{P_T}}{GLOW} - \left(\frac{W_{P_T}}{GLOW}\right)'$$ Use $P_{L/D} = + 0.1$
$$\frac{\Delta DOC_i/DOC_i}{\Delta(L/D)/(L/D)} = \frac{1}{P_{L/D}} \left[\frac{W_{PL}/GLOW}{(W_{PL}/GLOW)'} - 1 \right]$$ where, DOC_i = all DOC elements except DOC_P

TABLE 3-II.- "DRIVER PARTIAL" EQUATIONS - Concluded

(All terms are defined in TABLES 3-III and 3-IV)

For Driver I_{SP}

$$\frac{\Delta DOC_P/DOC_P}{\Delta I_{SP}/I_{SP}} = \frac{1}{P_{I_{SP}}}\left[\frac{\dfrac{1464\left\{\left(\dfrac{C_H + C_O\ (MR)}{(MR)+1}\right)\left(\dfrac{W_{P_T}}{GLOW}\right)''\right\}}{(LF)\ (W_{PL}/GLOW)''\ R_T}}{DOC_P} - 1\right]$$

where, $P_{I_{SP}} = \dfrac{\Delta I_{SP}}{I_{SP}}$

$$\left(\frac{W_{P_T}}{GLOW}\right)'' = \frac{1}{K_P}\left(1 - \frac{1}{e^A}\right)$$

where $A = \left\{\dfrac{1}{\left(1 + P_{I_{SP}}\right) I_{SP}}\left(808.67\left[1 - \dfrac{1}{e^B}\right]^{1/2} + 160.28 - 33.03 \sin \emptyset \cos \theta\right)\right\}$

and $B = \left\{\dfrac{R_T}{1082\ (L/D)\left(1 + \dfrac{0.2}{L/D}\right)}\right\}$

$$\left(\frac{W_{PL}}{GLOW}\right)'' = \left(\frac{W_{PL}}{GLOW}\right) + \left(\frac{W_{P_T}}{GLOW}\right) - \left(\frac{W_{P_T}}{GLOW}\right)''$$

Use $P_{I_{SP}} = +\ 0.02$

$$\frac{\Delta DOC_i/DOC_i}{\Delta I_{SP}/I_{SP}} = \frac{1}{P_{I_{SP}}}\left[\frac{W_{PL}/GLOW}{(W_{PL}/GLOW)''} - 1\right]$$

where, DOC_i = all DOC elements except DOC_P

$$\frac{\Delta DOC_{BL}/DOC_{BL}}{\Delta Driver_j/Driver_j} = \sum_i \frac{\left(\dfrac{\Delta DOC_i/DOC_i}{\Delta Driver_j/Driver_j}\right)(DOC_i)}{DOC_{BL}}$$

Input Data

Input data for this method module consist of the vehicle and mission parameters listed in Table 3-III which are provided by the output of Module 2, Baseline BGT Definition (reference Table 2- II). Other operational and cost factors required for solution of the DOC and Driver Partial formulas are given in Table 3-IV. Rationale for determining values for these parameters is discussed in Appendix 3-C.

Procedures

The procedures of this Method Module consist of solving the DOC formulas and Driver Partial equations and compiling the results in appropriate format for delivery to the Project Office.

1. DOC Formulas.- Determine the baseline DOC value for each of the DOC elements using the formulas listed in Table 3-I. Enter the values for the DOC elements at locations (a) in Column (1) of the Work Sheet, Table 3-V. Sum the DOC elements to give the total DOC, (DOC_{BL}) and enter in Column (1) of Table 3-V at location (b).

2. Driver Partials.-

   A. For Drivers, $\frac{W_{AF}}{GLOW}$, $(W/A)_{TPS}$, $(W/T)_{ME}$, L/D, and I_{SP} -

   Determine the Driver Partial for each Driver Parameter and DOC element using the Driver Partial equations in Table 3-II.

   NOTE: Table 3-II gives values to use for P_j = ΔDriver/Driver, the proportional improvement in each $Driver_j$, which linearizes the Driver Partials about the given values of P_j. These values of P_j result in a good approximation (accuracies consistent with the method) to the Driver Partials for projected improvements as follows.

TABLE 3-III.- INPUT DATA REQUIRED FOR METHOD MODULE 3

Symbol	Value		Parameter
Driver Parameter			
I_{SP}	$\frac{N\text{-sec}}{kg}$	$\frac{lb_f\text{-sec}}{lb_m}$	Main engine specific impulse (vacuum)
L/D	-		Lift-drag ratio (hypersonic)
W_{AF}/GLOW	-		Airframe weight fraction
L_{TPS}		year	Thermal protection system life
$(W/A)_{TPS}$	kg/m^2	(lb/ft^2)	Thermal protection system average weight per unit area
$(W/T)_{ME}$	kg/N	(-)	Weight to thrust ratio for main engines
Other Vehicle Parameters			
A_{TPS}	m^2	(ft^2)	Total area of surface protected by TPS
A_i	m^2	(ft^2)	*Area of surface protected by TPS against temperature, i
T_i	K	(°F)	*Maximum temperature of surface area, A_i
GLOW	kg	(lb)	Gross lift-off weight
K_P	-		Propellant factor, ratio of propellant used by main engines to total propellants on-board
MR	-		Mixture ratio for main engine propellants LO_2 to LH_2, by weight

*These terms required for pricing the TPS, using formula in Appendix 3-C, if desired.

TABLE 3-III.- INPUT DATA REQUIRED FOR METHOD MODULE 3 - Concluded

Symbol	Value	Parameter
N_{ME}	-	Number of main engines
N_{TJ}	-	Number of turbojet engines
R_T	km (st. miles)	Operational range
t_F	hours	Time of flight
T_{ME}	N (lb)	Main engine thrust (vacuum), per engine
T_{TJ}	N (lb)	Turbojet engine thrust (SL static) per engine
$(T/W)_{GLOW}$	N/kg (-)	Thrust to weight ratio at lift-off
$W_{AV}/GLOW$	-	Avionics weight fraction
$W_{Misc}/GLOW$	-	Equipment and subsystem weight fraction
$W_{PL}/GLOW$	-	Payload weight fraction
$W_{P_T}/GLOW$	-	Total on-baord propellant weight fraction
$W_S/GLOW$	-	Structure weight fraction

TABLE 3-IV.- COST AND OPERATIONAL FACTORS REQUIRED FOR SOLUTION FOR DOC AND DRIVER PARTIAL FORMULAS

Symbol	Units	Parameter	Suggested Value for Use, unless specified otherwise by Module 1 (See Appendix (C))
C_{AV}/GLOW	\$/kg (\$/lb)	Ratio, cost of avionics to gross lift-off weight	Use cost estimating relationships in Appendix C, or other source
C_{BGT}/GLOW	\$/kg (\$/lb)	Ratio, cost of BGT (total) to gross lift-off weight	
C_{Eq}/GLOW	\$/kg (\$/lb)	Ratio, cost of equipment and subsystems, (excl. main engines, turbojets, TPS, and avionics) to gross lift-off weight	
C_{ME}/GLOW	\$/kg (\$/lb)	Ratio, cost of main engines per BGT to Gross lift-off weight	
C_S/GLOW	\$/kg (\$/lb)	Ratio, cost of structure to gross lift-off weight	
C_{TJ}/GLOW	\$/kg (\$/lb)	Ratio, cost of turbojet engine set per BGT to gross lift-off weight	
C_{TPS}/GLOW	\$/kg (\$/lb)	Ratio, cost of thermal protection system to gross lift-off weight	
C_H	\$/kg (\$/lb)	Cost per unit weight of liquid hydrogen propellant	0.176 (0.08)
C_O	\$/kg (\$/lb)	Cost per unit weight of liquid oxygen propellant	0.0264 (0.012)
F_{OH}	Flights	Mean number of flights between main engine overhaul	500
IR	%/100	Annual insurance rate	0.02
LF	%/100	Average load factor	0.6
L_d	years	Assigned depreciation life of BGT	10

TABLE 3-IV.- COST AND OPERATIONAL FACTORS REQUIRED FOR SOLUTION FOR DOC AND DRIVER PARTIAL FORMULAS - Concluded

Symbol	Units	Parameter	Suggested Value for Use, Unless specified otherwise by Module 1 (See Appendix (C))
r_L	\$/hour	Average labor rate for all maintenance personnel	5.62
R_{OH}	-	Ratio, cost of overhaul to initial cost of main engines	0.15
U	flight hrs/ year	BGT utilization	1000
$\emptyset$	degrees	Launch azimuth (North = 0°, East = 90°, . . .)	90°
θ	degrees	Lattitude of launch	0°
K_{TPS}	-	Fraction of original TPS manufacturing cost required per flight FOR TPS maintenance	0.0006

TABLE 3-V.- WORK SHEET

	Baseline DOC Values- $ per Ton-Mile	Driver Partials for Driver Parameters				
		$\frac{W_{AF}}{GLOW}$	$\left(\frac{W}{A}\right)_{TPS}$	$\left(\frac{W}{T}\right)_{ME}$	L/D	I_{SP}
Column →	(1)	(2)	(3)	(4)	(5)	(6)
DOC_P	(a)					
Driver Partial		(c)				
Driver Partial x DOC_P		(d)				
DOC_C						
Driver Partial						
Driver Partial x DOC_C						
DOC_I						
Driver Partial						
Driver Partial x DOC_I						
DOC_D						
Driver Partial						
Driver Partial x DOC_D						
$DOC_{M/AF/L}$						
Driver Partial						
Driver Partial x $DOC_{M/AF/L}$						
$DOC_{M/AF/M}$			Note: Parenthetical entries (a), (b), . . are correlated to procedures.			
Driver Partial						
Driver Partial x $DOC_{M/AF/M}$						
$DOC_{M/ME}$						
Driver Partial						
Driver Partial x $DOC_{M/ME}$						

TABLE 3-V.- WORK SHEET - Concluded

	Baseline DOC Values- $ per Ton-Mile	Driver Partials for Driver Parameters				
		$\frac{W_{AF}}{GLOW}$	$\left(\frac{W}{A}\right)_{TPS}$	$\left(\frac{W}{T}\right)_{ME}$	L/D	I_{SP}
Column →	(1)	(2)	(3)	(4)	(5)	(6)
$DOC_{M/TPS}$ Driver Partial Driver Partial x $DOC_{M/TPS}$						
$DOC_{M/TJ}$ Driver Partial Driver Partial x $DOC_{M/TJ}$						
TOTAL DOC_{BL} Σ(Driver Partial x DOC_i)	(b)	(e)				
Driver Partial (total) (= Σ (Dr. Partial x DOC_i) /DOC_{BL})		(f)				

For Driver:	Improvement	P_j
W_{AF}	to 15%	0 to -0.15
$(W/A)_{TPS}$	to 20%	0 to -0.20
$(W/T)_{ME}$	to 20%	0 to -0.20
L/D	to 20%	0 to +0.20
I_{SP}	to 3%	0 to +0.03

For projected improvements greater than the above amounts, obtain the value of the projected improvement (ΔDriver/Driver) from the output of Module 5 for use in the Driver Partial equations.

Compile the results in columns (2) through (6) of the Work Sheet, Table 3-V, using the following steps:

- o Enter the Driver Partials from the solutions of the Driver Partial equations in columns (2) through (6), locations(c), for each Driver and DOC element.

- o Calculate (Driver Partial) x DOC_i for each Driver and DOC element (i) at locations(d).

- o Sum the values of (Driver Partial) x DOC_i for each of the Driver Partials and enter the total in the second line from the bottom of the Work Sheet (e).

- o Calculate the Driver Partial total for each Driver by dividing the entries of (e) above by the baseline DOC total (DOC_{BL}), and enter at the bottom of the Work Sheet (f).

B. For the Driver L_{TPS} -

In this case, an approximation for the proportional improvement in the Driver,

$$\frac{\Delta L_{TPS}}{L_{TPS}} = P_{L_{TPS}} ,$$

cannot be used because of the potential variation in the projected magnitude of the improvements.

Carry the following formula for the Driver Partial total forward to Module 6 where it is to be evaluated using the projection of the improvement in the Driver L_{TPS} from Module 5.

$$\frac{\Delta DOC_{BL}/DOC_{BL}}{\Delta L_{TPS}/L_{TPS}} = \left(\frac{\Delta DOC_{M/TPS}/DOC_{M/TPS}}{\Delta L_{TPS}/L_{TPS}}\right) \times \left(\frac{DOC_{M/TPS}}{DOC_{BL}}\right)$$

$$= \left[\frac{\frac{1}{L_{TPS}}}{K_{TPS} + \frac{1}{L_{TPS}}}\right]\left(\frac{-1}{1 + P_{L_{TPS}}}\right) \times \left(\frac{DOC_{M/TPS}}{DOC_{BL}}\right)$$

(Note that $\Delta DOC_{BL} = \Delta DOC_{M/TPS}$ because the Driver L_{TPS} appears only in the DOC formula $DOC_{M/TPS}$. Other $\Delta DOC_i = 0$ for the Driver L_{TPS}.)

Output Data

The output data required from Module 3 and carried forward to Module 6 includes DOC_{BL}, and the Driver Partials (totals) taken from the bottom of the Work Sheet, Table 3-V. In addition, the Driver Partial equation for the Driver L_{TPS} is carried forward so that it can be evaluated using the actual projected improvement in L_{TPS},

$$P_{L_{TPS}} = \frac{\Delta L_{TPS}}{L_{TPS}} ,$$

from Module 5. The value of $DOC_{M_{TPS}}$ is also carried forward and is required for solution of the Driver Partial equation for L_{TPS}.

Table 3-VI, completed with the above data, consitutes the output of Module 3 and is to be forwarded to the Project Office.

TABLE 3-VI.- OUTPUT DATA FROM MODULE 3

Baseline DOC ¢/ton-mile		Driver Partials for Drivers:				
DOC_{BL}	$DOC_{M/TPS}$	$\frac{W_{AF}}{GLOW}$	$\left(\frac{W}{A}\right)_{TPS}$	$\left(\frac{W}{T}\right)_{ME}$	L/D	I_{SP}

Driver Partial equation for Driver, L_{TPS}:

$$\frac{\Delta DOC_{BL}/DOC_{BL}}{\Delta L_{TPS}/L_{TPS}} = \left[\frac{\frac{1}{L_{TPS}}}{K_{TPS} + \frac{1}{L_{TPS}}}\right]\left(\frac{-1}{1 + P_{L_{TPS}}}\right)\left(\frac{DOC_{M/TPS}}{DOC_{BL}}\right)$$

DEMONSTRATION

This section provides an illustration of how the procedures of this Method Module are to be applied.

Input Data

The "Input Data" requirements are taken from the output of the Demonstration section of Module 2 of this report, "Baseline BGT Definition," (reference Table 2-VI). The input data values for the module are given in Table 3-VII.

Procedures

The first step in the procedure is the solution of the DOC equations. As these are solved, the results are entered in column (1) of the Work Sheet which is illustrated in Table VIII. For example, the first DOC equation is DOC propellant.

$$DOC_P = \frac{1464 \left[\left(\frac{C_H + C_O \ (MR)}{(MR) + 1} \right) \frac{W_{P_T}}{GLOW} \right]}{(LF) \ (W_{PL}/GLOW) \ R_T} \quad \$/\text{ton-st. miles}$$

The solution of the DOC propellant (DOCp) equation gives a value of \$0.59 per ton-mile direct operating cost for fuel. DOC_P and the values derived from the other DOC equations are entered in column (1) of the Work Sheet, Table 3-VIII, and summed, giving a total DOC_{BL} for operating the baseline BGT aircraft of 1.838 \$/ton-st. mile.

Values for all parameters required for solution of the equations are either inputs to the Method Module (reference Table 3-VII) or an appropriate value is given in Table 3-IV and Appendix 3-C.

The next step in the Method Module procedure is the solution of the Driver Partial equations except that for the Driver L_{TPS}. These have been solved in a manner similar to the DOC equations with inputs from Tables 3-VII or 3-IV.

TABLE 3-VII.- INPUT DATA REQUIRED FOR METHOD MODULE 3 - DEMONSTRATION DATA (Reference TABLE 3-III)

Symbol	Value	Parameter
Driver Parameters		
I_{SP}	$4560 \frac{N\text{-sec}}{kg} \left(465 \frac{lb_f\text{-sec}}{lb_m}\right)$	Main engine specific impulse (vacuum)
L/D	3.0	Lift-drag ratio (hypersonic)
$W_{AF}/GLOW$	0.0816	Airframe weight fraction
L_{TPS}	500 flights	Thermal protection system life
$(W/A)_{TPS}$	5.1 kg/m^2(1.09 lb/ft^2)	Thermal protection system average weight per unit area
$(W/T)_{ME}$	0.00137 kg/N (0.01347)	Weight to thrust ratio for main engines
Other Vehicle Parameters		
A_{TPS}	4653 m^2 (47 920 ft^2)	Total area of surface protected by TPS
A_1	736 m^2 (7924 ft^2)	*Area of surface protected by TPS against temperature, T_1, T_2, T_3, T_4
A_2	1182 m^2 (12 750 ft^2)	
A_3	675 m^2 (7288 ft^2)	
A_4	1555 m^2 (16 770 ft^2)	
T_1	1600-1800 K - (2500-2800 °F)	*Maximum temperature of surface area, 1, 2, 3, 4
T_2	1100-1600 K - (1500-2500 °F)	
T_3	700-1100 K - (800-1500 °F)	
T_4	250-700 K - (0-800 °F)	

*These terms required for pricing TPS using formula in Appendix C, if desired.

TABLE 3-VII.- INPUT DATA REQUIRED FOR METHOD MODULE 3 - DEMONSTRATION DATA (Reference TABLE 3-III) - Concluded

Symbol	Value	Parameter
GLOW	1 814 400 kg - (4 000 000 lb)	Gross lift-off weight
K_P	0.98	Propellant factor, ratio of propellant used by main engines to total propellant on-board
MR	6	Mixture ratio for main engine propellants LO_2 to LH_2, by weight
N_{ME}	12	Number of main engines
N_{TJ}	4	Number of turbojet engines
R_T	17 190 km - (10 680 st.-miles)	Operational range
t_F	1.4 hr	Time of flight
T_{ME}	1 856 000 N - (417 300 lb)	Main engine thrust (vacuum) per engine
T_{TJ}	200 200 N - (45 000 lb)	Turbojet engine thrust (SL static) per engine
$(T/W)_{GLOW}$	$12.28 \frac{N}{kg}$ (1.25)	Thrust to weight ratio at lift-off
$W_{AV}/GLOW$	0.00103	Avionics weight fraction
$W_{Eq}/GLOW$	0.1573	Equipment and subsystems weight fraction
$W_{PL}/GLOW$	0.0105	Payload weight fraction
$W_{P_T}/GLOW$	0.8512	Total on-board propellant weight fraction
$W_S/GLOW$	0.4823	Primary structure weight fraction
K_{TPS}	0.0006	Fraction of mfg. cost per flight for maintenance

TABLE 3-VIII.- WORK SHEET - DEMONSTRATION DATA (Reference TABLE 3-V)

	Baseline DOC Values- $ per Ton-Mile	Driver Partials for Driver Parameters				
		$\frac{W_{AF}}{GLOW}$	$\left(\frac{W}{A}\right)_{TPS}$	$\left(\frac{W}{T}\right)_{ME}$	L/D	I_{SP}
Column →	(1)	(2)	(3)	(4)	(5)	(6)
DOC_P	0.590	-	-	-	-	-
Driver Partial	-	4.37	1.11	1.38	-3.20	-18.40
Driver Partial x DOC_P	-	2.58	0.65	0.81	-1.89	-10.86
DOC_C	0.00815	-	-	-	-	-
Driver Partial	-	4.37	1.11	1.38	-3.16	-18.18
Driver Partial x DOC_C	-	0.036	0.009	0.011	-0.026	-0.148
DOC_I	0.0557	-	-	-	-	-
Driver Partial	-	4.37	1.11	1.38	-3.16	-18.18
Driver Partial x DOC_I	-	0.243	0.062	0.077	-0.176	-1.013
DOC_D	0.234	-	-	-	-	-
Driver Partial	-	4.37	1.11	1.38	-3.16	-18.18
Driver Partial x DOC_D	-	1.023	0.260	0.323	-0.739	-4.254
$DOC_{M/AF/M}$	0.0181	-	-	-	-	-
Driver Partial	-	4.37	1.11	1.38	-3.16	-18.18
Driver Partial x $DOC_{M/AF/M}$		0.079	0.020	0.025	-0.057	-0.329
$DOC_{M/AF/L}$	0.0134	-	-	-	-	-
Driver Partial	-	4.72	1.11	1.38	-3.16	-18.18
Driver Partial x $DOC_{M/AF/L}$	-	0.063	0.015	0.018	-0.042	-0.244
$DOC_{M/ME}$	0.111	-	-	-	-	-
Driver Partial	-	4.37	1.11	1.38	-3.16	-18.18
Driver Partial x $DOC_{M/ME}$	-	0.485	0.123	0.153	-0.351	-2.018
$DOC_{M/TPS}$	0.806	-	-	-	-	-
Driver Partial	-	4.37	1.11	1.38	-3.16	-18.18
Driver Partial x $DOC_{M/TPS}$	-	3.522	0.895	1.112	-2.547	-14.653

TABLE 3-VIII.- WORK SHEET - DEMONSTRATION DATA
(Reference TABLE 3-V) - Concluded

	Baseline DOC Values- \$ per Ton-Mile	Driver Partials for Driver Parameters				
		$\frac{W_{AF}}{GLOW}$	$\left(\frac{W}{A}\right)_{TPS}$	$\left(\frac{W}{T}\right)_{ME}$	L/D	I_{SP}
Column →	(1)	(2)	(3)	(4)	(5)	(6)
$DOC_{M/TJ}$	0.00131	-	-	-	-	-
Driver Partial	-	4.37	1.11	1.38	-3.16	-18.18
Driver Partial x $DOC_{M/TJ}$	-	0.006	0.001	0.002	-0.004	-.0238
TOTAL	1.838					
DOC_{BL}	-					
Σ(Driver Partial x DOC_i)	-	8.037	2.035	2.531	-5.832	-33.54
Driver Partial (total) (= Σ (Dr. Partial x DOC_i) /DOC_{BL})	-	4.37	1.11	1.38	-3.17	-18.25

For example, for the Driver, W_{AF}/GLOW, (airframe weight fraction), the initial Driver Partial equation is:

$$\frac{\Delta DOC_P/DOC_P}{\Delta(W_{AF}/GLOW)/(W_{AF}/GLOW)} = \frac{\dfrac{W_{AF}}{GLOW}}{\dfrac{W_{PL}}{GLOW} - {}^{P}W_{AF}\left(\dfrac{W_{AF}}{GLOW}\right)}$$

Using the value ${}^{P}W_{AF} = -0.1$ given in the Procedures section, the solution to the initial Driver equation gives a value of

$$\frac{\Delta DOC_P/DOC_P}{\Delta(W_{AF}/GLOW)/(W_{AF}/GLOW)} = 4.37,$$

which indicates, for example, that a 10% decrease in the Driver, W_{AF}/GLOW, would yield a 43.7% decrease in ΔDOC_P. The value of the Driver Partial is entered in column (2) of the Work Sheet (Table 3-VIII) for DOC_P. The other Driver Partials are entered in the Work Sheet in a similar manner. The Driver Partials are multiplied by the appropriate DOC values. The products are summed and entered at the bottom of the Work Sheet. The sums are then divided by DOC_{BL} to give the Driver Partial (total) for each Driver at the bottom of the Work Sheet.

Output Data

The demonstration values for the output data from Module 3 are illustrated in Table 3-IX.

TABLE 3-IX.- OUTPUT FROM MODULE 3 - DEMONSTRATION DATA (Reference TABLE 3-VI)

Baseline DOC ¢/ton-mile		Driver Partials for Drivers:				
DOC_{BL}	$DOC_{M/TPS}$	$\frac{W_{AF}}{GLOW}$	$\left(\frac{W}{A}\right)_{TPS}$	$\left(\frac{W}{T}\right)_{ME}$	L/D	I_{SP}
1.838	0.806	4.37	1.11	1.38	-3.17	-18.25

Driver Partial equation for Driver, L_{TPS} :

$$\frac{\Delta DOC_{BL}/DOC_{BL}}{\Delta L_{TPS}/L_{TPS}} = \left[\frac{\frac{1}{L_{TPS}}}{K_{TPS} + \frac{1}{L_{TPS}}}\right]\left(\frac{-1}{1 + P_{L_{TPS}}}\right)\left(\frac{DOC_{M/TPS}}{DOC_{BL}}\right)$$

DOC COMPARISON

A comparison is made of the DOC values computed for the demonstration BGT baseline in Table 3-X. The DOC values for the subsonic aircraft and the hypersonic aircraft are taken from reference 1. All the values are computed at a 60% load factor.

Corresponding values on a per seat mile basis can be computed by dividing the ¢ per ton-mile figures by 9 to convert tons of payload to equivalent total lbs per seat (≈ 222 lbs) and multiplying by 0.6 to compensate for the fact that the above values are all based on a 60% load factor. Usage of the term "seat miles" implies all seats occupied. "Passenger miles" implies use of a load factor, i.e., average proportion of seats occupied. The total costs per seat mile for the vehicles in Table 3-X are:

Subsonic (747 class) -	0.84¢
HST -	3.12
BGT -	12.3

TABLE 3-X.- COMPARATIVE DOC VALUES

	¢/ton st. mile		
	Subsonic (747 Class)	HST	BGT
Propellant	5.0	25.7	59.0
Crew	1.5	1.0	0.82
Insurance	0.7	2.1	5.57
Depreciation	2.9	12.0	23.4
Maintenance:			
M/AF/L	0.6	0.6	1.34
M/AF/M	0.5	1.5	1.81
M/ME	-	-	11.1
M/TJ	1.4	1.1	0.13
M/RJ	-	2.8	-
M/TPS	-	-	80.6
Total	12.6	46.8	183.9

SENSITIVITY

The purpose of this section is to discuss the sensitivity of the method to the selection of values for the cost and operational factors presented in Table 3-IV which are treated as constants in the DOC and Driver Partial equations.

A comparison of DOC_{BL} and Driver Partials is presented in Table 3-XI computed using the values of the cost and operational factors given in Table 3-IV and using the percentage revision in these factors given in Table 3-XI.

The magnitude of DOC_{BL} is, of course, greatly influenced by the values set on the cost and operational factors; however, the method is concerned with the change in DOC related to Technology Parameters. The values of the Driver Partials are relatively constant for changes in the cost and operational factors and where there are changes in the magnitude of the Driver Partials, their relative magnitude (rank order) is fairly constant. As a consequence, the relative importance of Driver Parameters and, in turn, Technology Parameters as indicated by the method is relatively insensitive to the selection of values for the cost and operational factors.

TABLE 3-XI.- SENSITIVITY OF DOC AND DRIVER PARTIALS TO COST AND OPERATIONAL FACTORS

Cost and Operational Factor	Rev. in Factor %	DOC_{BL} \$/ton st.mile	Driver Partial for Drivers:					
			$\frac{W_{AF}}{GLOW}$	$\left(\frac{W}{A}\right)_{TPS}$	$\left(\frac{W}{T}\right)_{ME}$	L/D	I_{SP}	L_{TPS} (1)
Values from Table 3-IV	(None)	1.838	4.37	1.11	1.38	-3.17	-18.25	-0.04
Revised value in factor:			(Percentage Change in Driver Partial)					
$C_{BGT}/GLOW$	±33%	1.930 1.745	0					
$C_{Eq}/GLOW$	±33%	1.840 1.836	0					
$C_{ME}/GLOW$	±33%	1.842 1.834	0					
$C_S/GLOW$	±33%	1.841 1.834	0					
$C_{TJ}/GLOW$	±33%	-	0					
$C_{TPS}/GLOW$	+33% -67%	2.104 1.298	0					
C_H	±20%	1.900 1.776	0	0	0	±3.4%	±3.4%	0
C_O	±20%	1.894 1.803	0	0	0	±3%	±3%	0
L_{TPS}	+200%	1.435	0					
IR	±50%	1.866 1.810	0					
LF	±33%	1.382 2.445	0					
L_d	±20%	1.799 1.885	0					
r_L	±20%	1.841 1.834	0					
R_{OH}	±50%	1.894 1.782	0					
U	±50%	1.604 2.072	0					
ϕ = 270° (W)	-	2.801	0					
θ = 60° (Lat.)	-	2.219	0					

(1) Using $\Delta L_{TPS}/L_{TPS} = P_{L_{TPS}} = 10$

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APPENDIX 3-A

DERIVATION OF DOC FORMULAS

The development of the DOC formulas is based on the ground rules for the BGT operation and costing presented in Table 3-A-I.

The Air Transport Association of America (ATA) presents procedures for organizing and estimating DOC for commercial airplanes (reference 2). The DOC formulas developed in the present study are organized in a manner generally consistent with the ATA method. Fuel costs are based on the unit cost of fuel times the quantity used. The quantity to be used has been developed in Module 2 with direct application to the BGT configuration. Crew, insurance, depreciation, airframe maintenance, and turbojet engine maintenance costs are based on extensions of the ATA method to the BGT case. A further subdivision of maintenance costs has been made to include main engine maintenance and thermal protection system maintenance. DOC for the latter two categories have been based on Space Shuttle program cost estimates (proposal period) with the introduction of a 90% learning curve factor applicable to 100 units and with the introduction of judgment-based factors to make the costs applicable to a commercial operation as opposed to the proposed Shuttle space flight operation.

The DOC formulas give DOC in units of dollars per ton statute mile consistent with current airline industry usage. All coefficients are given in the English system in this appendix.

The development of the DOC formulas are initially expressed in terms of cost per flight. These are converted to cost per ton mile by the introduction of the terms:

LF = load factor, W_{PL} = payload, and R = operational range,

in the denominator with appropriate constants to give DOC in ¢/ton statute mile. The numerator and denominator of the formulas have been divided by GLOW (gross-lift-off-weight) in order to normalize the weight terms.

Propellant Cost, P

The cost of propellant per flight is expressed simply as the unit cost times the quantity used.

TABLE 3-A-I.- COSTING GROUND RULES FOR THE BGT OPERATION

- Costs are based on the BGT operating in a commercial airline operational concept
- Categories of DOC will be consistent with current airlines' practice: propellant, crew, insurance, depreciation and maintenance
- Turn around, servicing and launch costs are an indirect operating cost (IOC), consistent with current airline practice, wherein ramp personnel and aircraft servicing are an IOC
- Launch control and flight monitoring systems will be furnished by governmental authorities in the manner that traffic control services are provided for airlines today
- Vertical launch facilities and terminals will be provided by local government authorities, and paid for on a fee basis as an IOC as airline terminal facilities are today
- Transporter-erector vehicles will be furnished by each airline, as capital items with interest and depreciation expense in IOC
- Pre-launch checkout and monitoring equipment will be self-contained and onboard the BGT
- Costs will be based on current 1973 dollar levels

Then

$$DOC_P = \frac{2000 \left(\frac{C_H + C_O \ (MR)}{(MR) + 1} \right) \frac{W_{P_T}}{GLOW}}{LF \ (W_{PL}/GLOW) \ R_T}$$

where

$W_{P_T}/GLOW$ = propellant weight fraction (total propellant on-board)

C_H = cost of liquid hydrogen, \$/lb

C_O = cost of liquid oxygen, \$/lb

MR = mixture ratio oxygen to hydrogen

The term $[C_H + C_O \ (MR)]/[(MR) + 1]$ is the weighted average unit cost of the hydrogen and oxygen propellant on-board. Although the turbojets will use hydrogen propellant only, it was found that pricing the turbojet propellant separately had a negligible impact on DOC_P; therefore, all propellant is priced at the weighted average cost.

Crew Cost, C

Crew costs include crew salary, fringe benefits, training programs, and travel expense. It is assumed that the BGT will have a crew of three which is the number assumed for the HST (reference 1). Stewardess' costs associated with passenger airlines are classified as a "Passenger Service" cost which is an indirect operating cost under CAB classification and not part of DOC.

The following annual crew salaries are postulated:

	Subsonic (747 class.)	HST	BGT
Pilot	\$ 45,000	\$ 54,000	\$ 60,000
1st officer	40,000	50,000	55,000
2nd officer	40,000	46,000	53,000
	\$ 125,000	\$ 150,000	\$ 168,000

An additional 30% is to be included for fringe benefits, training, and travel expense.

For the subsonic (747 class.), it is assumed that the crew flies 50 block hours per month = 600 hours per year; (block hour = flight time plus taxi time.) Then (1.30 x \$125,000)/600 = \$271 per block hour, which compares favorably with \$275 per block hour for commercial 747 crews for the first 9 months of 1972 (reference 3).

For the BGT, it is assumed that the crew flies approximately 25 hours per month. Assumptions that subsonic crews work 5 hours for 4 hours of flight (i.e., sign in one hour before flight), that BGT crews work 4 hours for 1.5 hours of flight, giving consideration to the longer pre-launch service and checkout time plus preflight preparation, and that BGT crews work the same total number of hours as the subsonic crews would result in BGT crews flying 23.4 hours per month which has been rounded to 25 hours per month or 300 hours per year. Then, BGT crew costs are:

$$\frac{1.3 \times \$168{,}000}{300 \text{ hrs.}} \approx \$728 \text{ per flight hour}$$

Assuming an average of t_F hours per flight

$$DOC_C = \frac{\$728 \times t_F \times 2000/GLOW}{(LF)\left(W_{PL}/GLOW\right) R_T}$$

$$\boxed{DOC_C = \frac{\left(1.456 \times 10^6/GLOW\right) t_F}{(LF)\ (W_{PL}/GLOW)\ R_T}}$$

Insurance Cost, I

Insurance cost covers insurance of the flight vehicle itself and is calculated simply as an annual rate times the acquisition cost of the vehicle.

Annual insurance cost = IR (C_{BGT})

where

IR = the annual insurance rate

C_{BGT} = cost of the flight vehicle

Then, for the BGT,

$$\boxed{DOC_I = \frac{IR\ (C_{BGT}/GLOW)\ 2000}{(LF)(W_{PL}/GLOW)\ U(R_T/t_F)}}$$

where

U = utilization of the aircraft in flight hours per year

t_F = average hours per flight

$U(R_T/t_F)$ = miles flown per year

Depreciation Cost, D

Depreciation cost is an expense provided to recover the original acquisition cost of the flight vehicle, plus the initial stock of spare parts, over an assigned depreciation life of the vehicle. (Subsequent purchase of spares to replace spares used from the initial stock are a maintenance expense.) The ATA formula includes 10% of the air vehicle cost less engines plus 40% of turbojet engine costs for the initial spares stock. For the BGT, assume 40% of the main engine cost for initial spares stock but only 10% of the turbojet engines because of the limited use of the turbojets.

Then,

$$\text{depreciation cost per year} = \frac{1.1\ C_{BGT} + 0.3\ C_{ME}}{L_d}$$

where

C_{ME} = cost of the main engines, \$

L_d = assigned depreciation life, years

Dividing by,

$$\frac{R_T}{t_F}(U) = \text{miles flown per years},$$

and with the payload terms,

$$DOC_D = \frac{\left(1.1\ C_{BGT}/GLOW + 0.3\ C_{ME}/GLOW\right) t_F\ 2000}{(LF)(W_{PL}/GLOW)\ R_T\ U\ L_d}$$

$$\boxed{DOC_D = \frac{\left(2200\ C_{BGT}/GLOW + 600\ C_{ME}/GLOW\right)\ t_F}{(LF)(W_{PL}/GLOW)\ R_T\ U\ L_d}}$$

Airframe Maintenance Labor, M/AF/L

Airframe maintenance as used here includes the structure and equipment and subsystems exclusive of main engines, turbojet engines, and the thermal protection system insulation.

The ATA formula gives the following for maintenance labor of airplanes less engines:

$$\frac{MMH}{\text{Flight Cycle}} = \left[0.05\ \frac{W_{AF}}{1000} + 6 - \frac{630}{\left(\frac{W_{AF}}{1000} + 120\right)}\right] M^{1/2}$$

plus:

$$\frac{MMH}{\text{Flight Hour}} = 0.59 \left[\frac{MMH}{\text{Flight Cycle}}\right]$$

where

MMH = maintenance manhours

W_{AF} = aircraft weight excluding engines

M = Mach no.

The ATA applies this formula to both subsonic aircraft and SST class aircraft, with M set = 1 for subsonic aircraft. It was judged that the term $M^{1/2}$ provided a suitable complexity factor for application of the formula to the hypersonic transport HST (reference 1) and will also be suitable for the BGT.

Considering the average Mach no. for the BGT to be,

$$M_{average} = \frac{R_T}{t_F\ 680} \approx \frac{12\ 000 \text{ miles}}{1.5 \text{ hrs } (680 \text{ mi/hr})} \approx 12$$

and using $M^{1/2}$ as the complexity factor, we have

	Mach	Complexity Factor
Subsonic	1	1
SST	2.7	1.64
HST	6	2.45
BGT	12	3.46

This seems to yield a reasonable factor for the BGT.

In applying the formula to the BGT, it further seems reasonable to multiply the flight hour-related portion of the formula by a factor of 2 to allow for the 1 to 2 hour preflight operation of certain subsystems and the relatively higher stresses on structure during flight than occurs in airplanes.

$$\frac{MMH}{Flight} = \frac{MMH}{Flight\ Cycle} + 2\ t_F \left(\frac{MMH}{Flight\ Hour}\right)$$

Then, applying the above and separating W_{AF} into W_S, weight of structure, plus $W_{Eq} + W_{AV}$, weight of other equipment and subsystems,

$$\frac{MMH}{Flight} = (1 + 1.2\ t_F) \left(\frac{R_T}{680\ t_F}\right)^{1/2} \left(0.5 \frac{W_S+W_{Eq}+W_{AV}}{1000} - \frac{630}{\left(\frac{W_S+W_{Eq}+W_{AV}}{1000} + 120\right)} + 6\right)$$

Two additional adjustments are now made. First, the term $(630/[0.001 (W_S + W_{Eq} + W_{AV}) + 120])$ reduces the cost by only approximately 10% for vehicles the size of the BGT. For simplification, it is replaced by a factor of 0.9. Second, the additional weight of the BGT airframe over subsonic aircraft for which the formula was developed is primarily in structure and propellant tanks which will have proportionately less maintenance than equipment and subsystems. Assuming that the maintenance per pound of equipment and subsystems is 10 times that for structure, the term $W_S + W_{Eq} + W_{AV}$ is replaced by a weighted term $(0.182\ [W_S + 10\ (W_{Eq} + W_{AV})]$ to allow for this.

Then, with a labor rate per hour, r_L, this becomes

$$\frac{\text{Cost}}{\text{Ton mile}} = \frac{(0.9 + 1.08\ t_F)\left[\frac{.01W_S}{1000} + \frac{.09(W_{Eq} + W_{AV})}{1000} + 6\right] r_L \left(\frac{R_T}{680\ t_F}\right)^{1/2}}{(LF)(W_{PL}/2000)\ R_T}$$

and finally

$$\boxed{DOC_{M/AF/L} = \frac{(.069 + .083\ t_F)\left[\frac{0.01W_S}{GLOW} + 0.09\left(\frac{W_{Eq}}{GLOW} + \frac{W_{AV}}{GLOW}\right) + \frac{6000}{GLOW}\right] r_L}{(LF)\ \frac{W_{PL}}{GLOW}\ R_T^{1/2}\ t_F^{1/2}}}$$

Airframe Maintenance Material, M/AF/M

Airframe maintenance is defined here as it was under airframe maintenance labor. The ATA formulas for this category account for costs from two categories:

$$\frac{\text{Cost}}{\text{Flight Cycle}} = 6.24\ \frac{C_{AF}}{10^6}$$

and

$$\frac{\text{Cost}}{\text{Flight Hour}} = 3.08\ \frac{C_{AF}}{10^6}$$

where

C_{AF} = cost of the airplane less engines

As in the case of airframe maintenance labor, it appears reasonable to multiply the "per flight hour" portion of the above by 2 to allow for pre-launch operation and higher stresses during flight.

Then

$$\frac{\text{Cost}}{\text{Flight}} = (6.16\ t_F + 6.24)\ (C_{AF}/10^6)$$

Combining this with the other appropriate terms and replacing C_{AF} with $C_S + C_{Eq} + C_{AV}$

$$\boxed{DOC_{M/AF/M} = \frac{(12.4\ t_F + 12.5)\ (C_S + C_{Eq} + C_{AV})/GLOW}{(LF)(W_{PL}/GLOW)\ R_T \times 10^3}}$$

Main Engine Maintenance, M/ME

The main engine maintenance costs have been based principally on data derived from the Space Shuttle program, and discussions with Rocketdyne personnel who are developing the Shuttle main engines.

The engines are start-limited because of thermal cycling and start stresses. They are operating time limited primarily because of rotating machinery under high stresses. The Space Shuttle Main Engines (SSME) specifications (proposal period) call for 100 starts and 7-1/2 hours of operation. (At ≈ 6 minutes per flight in the BGT, 7-1/2 hours of operating time would give a 75 mission life.)

At 100 missions the SSME requires overhaul maintenance at an estimated cost of approximately 28% of original cost, nearly half of which is in inspection and requalification and acceptance test.

Periodic scheduled maintenance before overhaul has been estimated for the SSME at 100 manhours per Shuttle flight (3 engines) which covers inspection, automatic checkout, data analysis, and corrective actions. The figures are doubled to cover unscheduled maintenance requirements and $1500 per flight is added to cover the cost of materials.

For the purposes of application to the BGT, the following considerations and adjustments have been made.

The overhaul costs are estimated at 15% of acquisition costs based on the consideration that the 28% figure is based on today's policy with respect to quality control, inspection, test, and acceptance procedures. It is estimated that commercial procedures would reduce the cost by at least one-half.

A term for flights between overhaul, F_{OH}, has been included in the formula; however, it is considered its value should be increased from $\approx$100 flights to $\approx$600 flights. This number was suggested by Rocketdyne personnel for a repetitive commercial operation of the engine in future years. It is also considered that the engine maintenance other than overhaul should also be reduced in the same proportion to reflect anticipated improvement in a commercial operation. Other maintenance is, therefore, multiplied by ratio of 100/600. The above is not inconsistent with turbojet engine experience which started with 500-600 hours between planned overhauls and moved in a few years to 3000-4000 hours, a ratio of $\approx$ 6 to 1 and a comparable reduction has been found in all turbojet maintenance.

Finally, a thrust term has been included in the overall formula to relate the cost to the size of engines under consideration. The term used is

$$\left(\frac{T_{ME}}{\text{SSME Thrust, lbs}}\right)^{1/2} = \frac{\left(T_{ME}\right)^{1/2}}{685.6}$$

where

T_{ME} = thrust (vacuum) each engine

Development of a maintenance formula then becomes, for overhaul costs:

$$\text{Overhaul Cost/Flight} = \frac{R_{OH}\ C_{ME}}{F_{OH}}$$

where

R_{OH} = ratio overhaul cost to original cost of the engines

F_{OH} = flights between overhaul

C_{ME} = acquisition cost of the main engine set per vehicle

For maintenance other than scheduled overhaul:

$$\text{Other Cost/Flight} = \left[\frac{100\ \text{manhours}}{3\ \text{engines}} \times 2 \times r_L + \frac{\$1500}{3\ \text{engines}}\right] \frac{N_{ME}}{6}$$

where

N_{ME} = number of engines per BGT

Total cost, including the thrust term and ton-mile terms,

$$\frac{\text{Cost}}{\text{Ton-mile}} = \frac{\left[\frac{R_{OH}\ C_{ME}}{F_{OH}} + (11\ r_L + 83)\ N_{ME}\right] T_{ME}^{1/2}/685.6}{F_{OH}\ (LF)\ \frac{W_{PL}}{2000}\ R_T}$$

$$\boxed{DOC_{M/ME} = \frac{2.92\ T_{ME}^{1/2}\left[(R_{OH}/F_{OH})(C_{ME}/GLOW) + (11\ r_L + 83)\ N_{ME}/GLOW\right]}{(LF)\ (W_{PL}/GLOW)\ R_T}}$$

Maintenance, Thermal Protection System, M/TPS

The thermal protection system which covers the surface of the vehicle provides two basic functions : (1) re-radiation of the incident aerodynamic heat to the surrounding environment and (2) insulation of the primary load-carrying structure from the high temperature at the TPS surface.

Maintenance functions to be performed at the conclusion of each flight include:

(1) post-mission inspection, and

(2) replacement of defective TPS segments.

Post-mission inspection.- This will consist of a 100 percent non-destructive-test (NDT) of all TPS surfaces. The tests (e.g., ultrasonic) will inspect for fractures and permeability in the TPS surface coating; for nucleation or voids in the TPS matrix; and for delamination or fractures in the TPS bond line. For commercial operations of the boost-glide vehicle, it is projected that the tests will be automated within special facilities provided for that purpose. The only direct costs incurred would be those of test data interpretation by human operators.

Replacement of TPS segments. - Where defective segments are identified by the above tests, they shall be removed and replaced by flight-line operational techniques and certified for flight readiness.

In addition to the per-flight maintenance of the TPS, a total replacement of the TPS shall be scheduled, based upon its useful life, L_{TPS}. The parameter, L_{TPS}, is measured in numbers of flights between replacements and is a driver in the present method. The cost of replacement is assumed equal to the original manufacturing cost of materials and labor for installation of the TPS.

The total TPS maintenance cost then is given by the following expression:

$$\boxed{DOC_{M/TPS} = \frac{2000\ C_{TPS}/GLOW}{LF\ (W_{PL}/GLOW)\ R_T}\left(K_{TPS} + \frac{1}{L_{TPS}}\right)}$$

where,

K_{TPS} = fraction of original TPS manufacturing cost required per flight for TPS maintenance.

Turbojet Engine Maintenance, M/TJ

The turbojet engine maintenance formula is based on the current ATA formula. The ATA gives for,

Materials:

$$\frac{\text{Cost}}{\text{Flight Cycle}} = 2.5\ C_{TJ}/10^5$$

$$\frac{\text{Cost}}{\text{Flight Hour}} = 2.0\ C_{TJ}/10^5$$

where,

C_{TJ} = cost of turbojets per vehicle

Then,

$$\frac{\text{Cost}}{\text{Flight}} = 2.5\ C_{TJ}/10^5 + (2.0\ C_{TJ}/10^5)\ t_F$$

Labor:

$$\frac{\text{MMH}}{\text{Flight Cycle}} = (0.3 + 0.03\ T_{TJ}/10^3)\ N_{TJ}$$

$$\frac{\text{MMH}}{\text{Flight Hour}} = (0.6 + 0.027\ T_{TJ}/10^3)\ N_{TJ}$$

where,

MMH = maintenance manhours

T_{TJ} = thrust, each turbojet, lbs

N_{TJ} = Number of engines

For large turbojet engines, less than 10% difference exists between the above terms. They are, therefore, treated as equal for simplicity. Then, with time of flight, t_F, and inclusion of the labor rate, r_L,

$$\frac{\text{Cost}}{\text{Flight}} = (1 + t_F)(0.6 + 0.027\ T_{TJ}/10^3)\ N_{TJ}\ r_L$$

For the BGT flight, engine operating time will equal approximately one-half hours which is, therefore, substituted for t_F. Then, combining the expressions and including the ton-mile terms,

$$DOC_{M/TJ} = \frac{(3.5\ C_{TJ}/10^5) + (0.9 + 0.04\ T_{TJ}/10^3)\ N_{TJ}\ r_L}{LF\ (W_{PL}/2000)\ R_T}$$

Finally,

$$\boxed{DOC_{M/TJ} = \frac{0.07\ C_{TJ}/GLOW + \left[(1800 + 0.08\ T_{TJ})\ N_{TJ}\ r_L/GLOW\right]}{LF\ (W_{PL}/GLOW)\ R_T}}$$

APPENDIX 3-B

DERIVATION OF DRIVER PARTIALS

This appendix presents the derivation of the Driver Partials (ΔDOC/DOC)/(ΔDriver/Driver) which are presented in the Procedures section.

In the development of the Driver Partial equations, it is assumed that the acquisition cost of the BGT is not decreased by improvements in the technology. In other words, an improvement in engine performance would result in a smaller, but not a cheaper engine. It would, however, indirectly decrease DOC due to weight reductions which translate into increased payload fractions.

Each of the six Driver Parameters and their effects on all elements of DOC are treated in turn.

Airframe Weight Fraction, (W_{AF}/GLOW)

For a given size vehicle, reductions in airframe weight can be replaced by additional payload weight.

$$\frac{W_{AF}}{GLOW} = 1 - \frac{W_{ME}}{GLOW} - \frac{W_{TJ}}{GLOW} - \frac{W_{TPS}}{GLOW} - \frac{W_{P_T}}{GLOW} - \frac{W_{PL}}{GLOW} - \frac{W_{AV}}{GLOW} - \frac{W_{Misc.}}{GLOW}$$

and $\frac{W_{PL}}{GLOW} = 1 - \frac{W_{AF}}{GLOW} - \frac{W^*}{GLOW}$

where, $\frac{W^*}{GLOW}$ represents all weight terms other than $\frac{W_{PL}}{GLOW}$ and $\frac{W_{AF}}{GLOW}$.

Propellant cost.- The formula for DOC_P from Appendix 3-A is:

$$DOC_P = \frac{\left[\left(\frac{C_H + C_O\ (MR)}{(MR) + 1}\right)\frac{W_{P_T}}{GLOW}\right] 2000}{(LF)\ (W_{PL}/GLOW)\ R_T}$$

We wish to obtain

$$\frac{\Delta DOC_P/DOC_P}{\Delta Driver/Driver} \text{ for the Driver } \frac{W_{AF}}{GLOW}$$

DOC_P can be written,

$$DOC_P = \frac{A}{1 - \frac{W_{AF}}{GLOW} - \frac{W^*}{GLOW}}$$

where,

A represents all terms other than $\frac{W_{PL}}{GLOW}$

and

$$\frac{\Delta DOC_P}{DOC_P} = \frac{\dfrac{A}{1 - \boxed{\frac{W_{AF}}{GLOW} + \Delta \frac{W_{AF}}{GLOW}} - \frac{W^*}{GLOW}} - \dfrac{A}{1 - \frac{W_{AF}}{GLOW} - \frac{W^*}{GLOW}}}{\dfrac{A}{1 - \frac{W_{AF}}{GLOW} - \frac{W^*}{GLOW}}}$$

This reduces to:

$$\frac{\Delta DOC_P}{DOC_P} = \frac{\Delta \frac{W_{AF}}{GLOW}}{1 - \frac{W_{AF}}{GLOW} - \Delta \frac{W_{AF}}{GLOW} - \frac{W^*}{GLOW}}$$

Consider that,

$$\frac{W_{PL}}{GLOW} = 1 - \frac{W_{AF}}{GLOW} - \frac{W^*}{GLOW} \quad ,$$

and let,

$$P_{W_{AF}} = \frac{\dfrac{\Delta W_{AF}}{GLOW}}{\dfrac{W_{AF}}{GLOW}} = \text{the proportional improvement in the Driver } W_{AF}/GLOW,$$

and divide by $(\Delta W_{AF}/GLOW)/(W_{AF}/GLOW) = \Delta Driver/Driver$.

The above then reduces to:

$$\boxed{\frac{\Delta DOC_P/DOC_P}{\Delta(W_{AF}/GLOW)/(W_{AF}/GLOW)} = \frac{\dfrac{W_{AF}}{GLOW}}{\dfrac{W_{PL}}{GLOW} - P_{W_{AF}}\left(\dfrac{W_{AF}}{GLOW}\right)}}$$

<u>Crew cost</u>.- From Appendix 3-A,

$$DOC_C = \frac{(1.456 \times 10^6/GLOW)\left(t_F\right)}{(LF)\ (W_{PL}/GLOW)\ R_T}$$

As in the case of DOC_P, the only term affected by changes in the Driver, $W_{AF}/GLOW$ is the payload term. Thus, by similarity to the case for DOC_P

$$\boxed{\frac{\Delta DOC_C/DOC_C}{\Delta(W_{AF}/GLOW)/(W_{AF}/GLOW)} = \frac{\dfrac{W_{AF}}{GLOW}}{\dfrac{W_{PL}}{GLOW} - P_{W_{AF}}\left(\dfrac{W_{AF}}{GLOW}\right)}}$$

Insurance cost.- From Appendix 3-A,

$$DOC_I = \frac{2000\ IR\ (C_{BGT}/GLOW)\ t_F}{(LF)\ (W_{PL}/GLOW)\ R_T\ U}$$

By similarity to the above form,

$$\boxed{\frac{\Delta DOC_I/DOC_I}{\Delta(W_{AF}/GLOW)/(W_{AF}/GLOW)} = \frac{\frac{W_{AF}}{GLOW}}{\frac{W_{PL}}{GLOW} - P_{W_{AF}}\left(\frac{W_{AF}}{GLOW}\right)}}$$

Depreciation cost.- From Appendix 3-A,

$$DOC_D = \frac{2000\ t_F\left[1.1\ (C_{BGT}/GLOW) + 0.3\ (C_{ME}/GLOW)\right]}{(LF)\ (W_{PL}/GLOW)\ R_T\ U\ L_d}$$

Again, by similarity to the above form,

$$\boxed{\frac{\Delta DOC_D/DOC_D}{\Delta(W_{AF}/GLOW)/(W_{AF}/GLOW)} = \frac{\frac{W_{AF}}{GLOW}}{\frac{W_{PL}}{GLOW} - P_{W_{AF}}\left(\frac{W_{AF}}{GLOW}\right)}}$$

Airframe maintenance labor.- From Appendix 3-A,

$$DOC_{M/AF/L} = \frac{(0.069 + 0.083\ t_F)\left[0.01\left(\frac{W_s}{GLOW}\right) + 0.09\left(\frac{W_{Eq}}{GLOW} + \frac{W_{AV}}{GLOW}\right) + \left(\frac{6000}{GLOW}\right)\right] r_L}{(LF)\ (W_{PL}/GLOW)\ R_T^{1\ 2}\ t_F^{1\ 2}}$$

In this case

$$\frac{W_S}{GLOW} + \left(\frac{W_{Eq}}{GLOW} + \frac{W_{AV}}{GLOW}\right) = \frac{W_{AF}}{GLOW}$$

so that changes in the Driver, $\frac{W_{AF}}{GLOW}$

affect the numerator of the DOC equation as well as the payload term.

If the improvement in the Driver affected only the term, $W_{PL}/GLOW$ as in the prior cases, we would have,

$$\frac{\left(\Delta DOC_{M/AF/L}\right)/\left(DOC_{M/AF/L}\right)}{\Delta\left(W_{AF}/GLOW\right)/\left(W_{AF}/GLOW\right)} = \frac{\frac{W_{AF}}{GLOW}}{\frac{W_{PL}}{GLOW} - P_{W_{AF}}\left(\frac{W_{AF}}{GLOW}\right)}$$

Calculations for the baseline BGT indicate that the following is a good approximation to the correct value.

$$\boxed{\frac{\left(\Delta DOC_{M/AF/L}\right)/\left(DOC_{M/AF/L}\right)}{\Delta\left(W_{AF}/GLOW\right)/\left(W_{AF}/GLOW\right)} = \frac{1.08\left(\frac{W_{AF}}{GLOW}\right)}{\frac{W_{PL}}{GLOW} - P_{W_{AF}}\left(\frac{W_{AF}}{GLOW}\right)}}$$

$DOC_{M/AF/M}$, $DOC_{M/ME}$, $DOC_{M/TPS}$, and $DOC_{M/TI}$.- Examination of the DOC formulas for all of these cases reveals that the Driver $W_{AF}/GLOW$ affects only the payload term, $(W_{PL}/GLOW)$ in the denominators. Therefore, by similarity to the earlier forms,

$$\boxed{\frac{\Delta DOC_i / DOC_i}{\Delta\left(W_{AF}/GLOW\right)\Big/\left(W_{AF}/GLOW\right)} = \frac{\dfrac{W_{AF}}{GLOW}}{\dfrac{W_{PL}}{GLOW} - P_{W_{AF}}\left(\dfrac{W_{AF}}{GLOW}\right)}}$$

where,

$$DOC_i = DOC_{M/AF/M},\ DOC_{M/ME},\ DOC_{M/TPS},\ \text{and}\ DOC_{M/TJ}$$

Thermal Protection System Life, L_{TPS}

The Driver L_{TPS} appears in the DOC formula for maintenance of the TPS only, therefore, a change in its value will not affect the other DOC elements. Therefore,

$$\boxed{\frac{\Delta DOC_i / DOC_i}{\Delta L_{TPS} / L_{TPS}} = 0}$$

where,

$$DOC_i = DOC_P,\ DOC_C,\ DOC_I,\ DOC_D,\ DOC_{M/AF/L},\ DOC_{M/AF/M},\ DOC_{M/ME},\ \text{and}\ DOC_{M/TJ}$$

For $DOC_{M/TPS}$,

$$DOC_{M/TPS} = \frac{2000\ C_{TPS}/GLOW}{(LF)\ (W_{PL}/GLOW)\ R_T}\left(K_{TPS} + \frac{1}{L_{TPS}}\right)$$

from Appendix 3-A.

This can be written

$$DOC_{M/TPS} = \left(A + \frac{B}{L_{TPS}}\right)$$ Where A and B represent all terms other than L_{TPS}.

Then

$$\frac{\Delta DOC_{M/TPS}}{DOC_{M/TPS}} = \frac{A + \dfrac{B}{L_{TPS} + \Delta L_{TPS}} - A - \dfrac{B}{L_{TPS}}}{A + \dfrac{B}{L_{TPS}}}$$

and

$$\frac{\Delta DOC_{M/TPS}}{DOC_{M/TPS}} = \left[\frac{-B\Delta L_{TPS}}{\Delta L_{TPS} + B}\right]\left[\frac{1}{L_{TPS} + \Delta L_{TPS}}\right]$$

$$= -\left[\frac{B/L_{TPS}}{A + B/L_{TPS}}\right]\left[\frac{\Delta L_{TPS}}{L_{TPS} + \Delta L_{TPS}}\right]$$

$$\frac{\left(\dfrac{\Delta DOC_{M/TPS}}{DOC_{M/TPS}}\right)}{\left(\dfrac{\Delta L_{TPS}}{L_{TPS}}\right)} = -\left[\frac{B/L_{TPS}}{A + B/L_{TPS}}\right]\left(\frac{1}{1 + P_{L_{TPS}}}\right)$$

where

$$P_{L_{TPS}} = \frac{\Delta L_{TPS}}{L_{TPS}}$$

Now, from the original expression for $DOC_{M/TPS}$, we find

$$A = K_{TPS}\,X \qquad\qquad B = X$$

so

$$\frac{\left(\frac{\Delta DOC_{M/TPS}}{DOC_{M/TPS}}\right)}{\left(\frac{\Delta L_{TPS}}{L_{TPS}}\right)} = - \left[\frac{X/L_{TPS}}{K_{TPS}\,X + X/L_{TPS}}\right] \left(\frac{1}{1 - P_{L_{TPS}}}\right)$$

and finally

$$\frac{\left(\frac{\Delta DOC_{M/TPS}}{DOC_{M/TPS}}\right)}{\left(\frac{\Delta L_{TPS}}{L_{TPS}}\right)} = - \left[\frac{1/L_{TPS}}{K_{TPS} + 1/L_{TPS}}\right] \left(\frac{1}{1 + P_{L_{TPS}}}\right)$$

Weight per Unit Area of TPS, $(W/A)_{TPS}$

The TPS weight fraction

$$\frac{W_{TPS}}{GLOW} = (W/A)_{TPS}\ A_{TPS}/GLOW$$

and

$$\frac{W_{PL}}{GLOW} = 1 - (W/A)_{TPS} \left(\frac{A_{TPS}}{GLOW}\right) - \frac{W^{**}}{GLOW}$$

where $\frac{W^{**}}{GLOW}$ = all weight fraction terms other than $\frac{W_{PL}}{GLOW}$ and $\frac{W_{TPS}}{GLOW}$

Propellant cost.- From Appendix 3-A,

$$DOC_P = \frac{2000\left(\frac{C_H + C_O(MR)}{(MR)+1}\right)\left(\frac{W_{P_T}}{GLOW}\right)}{(LF)\ (W_{PL}/GLOW)\ R_T}$$

This can be written

$$DOC_P = \frac{A}{1 - \frac{(W/A)_{TPS} A_{TPS}}{GLOW} - \frac{W^{**}}{GLOW}}$$

where A represents all terms other than $\frac{W_{PL}}{GLOW}$

$$\frac{\Delta DOC_P}{DOC_P} = \frac{\frac{A}{1 - \left[\frac{(W/A)_{TPS}}{GLOW} + \frac{\Delta (W/A)_{TPS}}{GLOW}\right] A_{TPS} - \frac{W^{**}}{GLOW}} - DOC_P}{DOC_P}$$

Then in a manner similar to the case for DOCp under the Driver $\frac{W_{AF}}{GLOW}$,

$$\boxed{\frac{\Delta DOC_P/DOC_P}{\Delta (W/A)_{TPS}/(W/A)_{TPS}} = \frac{A_{TPS}\ (W/A)_{TPS}/GLOW}{\frac{W_{PL}}{GLOW} - P_{(W/A)_{TPS}}\ A_{TPS}\ (W/A)_{TPS}/GLOW}}$$

where $P_{(W/A)_{TPS}} = \frac{\Delta (W/A)_{TPS}}{(W/A)_{TPS}}$

<u>Other costs</u>.- By similarity to prior forms,

$$\boxed{\frac{\Delta DOC_i/DOC_i}{\Delta (W/A)_{TPS}/(W/A)_{TPS}} = \frac{A_{TPS}\ (W/A)_{TPS}/GLOW}{\frac{W_{PL}}{GLOW} - P_{(W/A)_{TPS}}\ A_{TPS}\ (W/A)_{TPS}/GLOW}}$$

where DOC_i = All DOC elements.

Main Engine Specific Weight $(W/T)_{ME}$

In the case of the Driver $(W/T)_{ME}$

$$\frac{W_{ME}}{GLOW} = (W/T)_{ME}\ (T/W)_{GLOW}$$

As in the prior cases for $W_{AF}/GLOW$ and $W_{TPS}/GLOW$, changes in main engine weight are reflected only in compensating changes in payload weight.

Then, by analogy to the earlier forms,

$$\boxed{\frac{\Delta DOC_i\ \ DOC_i}{\Delta (W/T)_{ME}/(W/T)_{ME}} = \frac{(W/T)_{ME}\ (T/W)_{GLOW}}{\frac{W_{PL}}{GLOW} - P_{(W/T)_{ME}}\ (W/T)_{ME}\ (T/W)_{GLOW}}}$$

where DOC_i = all DOC elements, (DOC_P, DOC_C, DOC_I, etc.).

$$P_{(W/T)_{ME}} = \frac{\Delta (W/T)_{ME}}{(W/T)_{ME}}$$

Lift-to Drag Ratio, L/D

Improvements in L/D affect DOC through the propellant weight term (W_{P_T}/GLOW) in the DOC_P formula. In addition, the reduced fuel weight can be traded pound for pound with payload and, therefore, affects all the DOC formulas through the payload weight fraction term (W_{PL}/GLOW).

Fuel cost.- The DOC fuel equation, from Appendix 3-A, is:

$$DOC_P = \frac{2000\left[\left(\frac{C_H + C_O\ (MR)}{(MR) + 1}\right)\frac{W_{P_T}}{GLOW}\right]}{(LF)\ (W_{PL}/GLOW)\ R_T}$$

where

$$\frac{W_{P_T}}{GLOW} = \frac{1}{K_P}\left(1 - \frac{1}{e^A}\right)$$

and

$$A = \frac{1}{I_{SP}}\left\{808.67\left[1 - \frac{1}{e^B}\right]^{1/2} + 160.28 - 33.03 \sin \phi \cos \theta\right\}$$

$$B = \frac{R_T}{1741.25\ (L/D)\left[1 + \frac{0.2}{(L/D)}\right]}$$

K_P = ratio of main engine fuel to total fuel on-board

I_{SP} = specific impulse

R_T = operational range

ϕ = launch azimuth

θ = launch lattitude

Let

$$\frac{\Delta DOC_P}{DOC_P} = \frac{(DOC_P)' - DOC_P}{DOC_P}$$

where (DOC)' is the revised DOC_P to reflect the improvement in L/D.

Then,

$$\boxed{\frac{\Delta DOC_P/DOC_P}{(\Delta L/D)/(L/D)} = \frac{1}{P_{L/D}}\left[\frac{\dfrac{\left\{\left(\dfrac{C_H + C_O\ (MR)}{(MR) + 1}\right)\left(\dfrac{W_{P_T}}{GLOW}\right)'\right\} 2000}{(LF)\ (W_{PL}/GLOW)'\ R_T}}{DOC_P} - 1\right]}$$

where,

$P_{L/D}$ = proportional improvement in the Driver, L/D

$$\left(\frac{W_{P_T}}{GLOW}\right)' = \frac{1}{K_P}\left(1 - \frac{1}{e^A}\right)$$

where

$$A = \frac{1}{I_{SP}}\left\{808.67\left[1 - \frac{1}{e^B}\right]^{1/2} + 160.28 - 33.03 \sin \emptyset \cos \theta\right\}$$

$$B = \frac{R_T}{1741.25\ (1 + P_{L/D})\ (L/D)\left[1 + \dfrac{0.2}{(1 + P_{L/D})(L/D)}\right]}$$

$$\left(\frac{W_{PL}}{GLOW}\right)' = \frac{W_{PL}}{GLOW} + \frac{W_{P_T}}{GLOW} - \left(\frac{W_{P_T}}{GLOW}\right)'$$

Other cost elements.- For all DOC elements other than DOC_P, improvements in L/D affect only the payload term through the reduction in the fuel requirement. The DOC equations can be written,

$$DOC_i = \frac{A}{W_{PL}/GLOW}$$

where A represents all terms other than $W_{PL}/GLOW$

$$\Delta DOC_i/DOC_i = \frac{(DOC_i)' - DOC_i}{DOC_i}$$

where $(DOC_i)'$ is the revised DOC_i due to the improvement in L/D

$$(DOC_i)' = DOC_i \frac{W_{PL}/GLOW}{(W_{PL}/GLOW)'}$$

and

$$\boxed{\frac{\Delta DOC_i/DOC_i}{(\Delta L/D)/(L/D)} = \frac{1}{P_{L/D}} \left[\frac{W_{PL}/GLOW}{(W_{PL}/GLOW)'} - 1\right]}$$

where,

$DOC_i = DOC_C$, DOC_I, DOC_D, $DOC_{M/AF/L}$, $DOC_{M/AF/M}$, $DOC_{M/ME}$, $DOC_{M/TPS}$, and $DOC_{M/TJ}$

$(W_{PL}/GLOW)'$ is as above for L/D

$P_{L/D} = \frac{\Delta L/D}{L/D}$ the proportional improvement in the Driver L/D

Specific Impulse, I_{SP}

By direct analogy to the case for L/D:

$$\boxed{\frac{\Delta DOC_P/DOC_P}{\Delta I_{SP}/I_{SP}} = \frac{1}{P_{I_{SP}}}\left[\frac{\dfrac{\left\{\left(\dfrac{C_H + C_O\ (MR)}{(MR) + 1}\right)\left(\dfrac{W_{P_T}}{GLOW}\right)''\right\}2000}{(LF)\ (W_{PL}/GLOW)''\ R_T}}{DOC_P} - 1\right]}$$

where,

$$P_{I_{SP}} = \frac{\Delta I_{SP}}{I_{SP}}$$, the proportional improvement in the Driver I_{SP}

$$\left(\frac{W_{P_T}}{GLOW}\right)'' = \frac{1}{K_P}\left(1 - \frac{1}{e^A}\right)$$

where,

$$A = \frac{1}{\left(1 + P_{I_{SP}}\right)(I_{SP})}\left\{808.67\left[1 - \frac{1}{e^B}\right]^{1/2} + 160.28 - 33.03 \sin \phi \cos \theta\right\}$$

$$B = \frac{R_T}{1741.25\ (L/D)\left[1 + \dfrac{0.2}{(L/D)}\right]}$$

$$\left(\frac{W_{PL}}{GLOW}\right)'' = \frac{W_{PL}}{GLOW} + \frac{W_{P_T}}{GLOW} - \left(\frac{W_{P_T}}{GLOW}\right)''$$

Other cost elements.- Again, by direct analogy to the case for the Driver L/D,

$$\boxed{\frac{\Delta DOC_i/DOC_i}{(\Delta I_{SP})/(I_{SP})} = \frac{1}{P_{I_{SP}}}\left[\frac{W_{PL}/GLOW}{(W_{PL}/GLOW)''} - 1\right]}$$

for the Driver I_{SP}

where,

$DOC_I = DOC_C, DOC_I, DOC_D, DOC_{M/AF/L}, DOC_{M/AF/M}, DOC_{M/ME}, DOC_{M/TPS},$ and $DOC_{M/TJ}$

$(W_{PL}/GLOW)''$ is as above for I_{SP}

$$P_{I_{SP}} = \frac{\Delta I_{SP}}{I_{SP}}$$

APPENDIX 3-C

OPERATIONAL CONSTANTS AND COST FACTORS

This appendix provides information about the operational constants and cost factors required for solution of the DOC formulas which are not defined by the baseline BGT definition. Rationale is provided for the values which are suggested in the Procedures section, Table 3-IV. The section on Sensitivity has indicated that although the value of DOC is sensitive to these factors, the relative impact of the drivers on DOC is not very sensitive to these factors; therefore, the comparative evaluation of technology improvements is not very sensitive to these factors. Nevertheless, "reasonable" rationale should be used in the selection of their values.

Operational Constants

Load factor, (LF).- Load factor is the ratio of the average payload carried to the maximum payload which the aircraft is capable of carrying in normal operation. The airline industry average load factor was about 50% (1972). However, the industry average has been depressed in recent years and is expected to improve. It was 44% in 1971 (reference 4). A value of 60% was used in the HST study (reference 1) and 60% has been used in the BGT baseline calculation.

Utilization, U.- Utilization is defined for the BGT as the average number of flight hours per year (lift-off to touchdown). Utilization rates for aircraft in the airline industry vary from about 3500 to 4500 hours per - year including taxitime. 3000 hours was used for the HST in the HST study (reference 1) because of the highspeed and relatively short flight time. 1000 hours has been used in the BGT baseline claculation.

A formula for utilization (reference 7) can be expressed simply as

$$U = \begin{matrix}\text{Available}\\ \text{time per year}\end{matrix} \times \left[\frac{\text{Flight time}}{\begin{matrix}\text{Flight}\\ \text{Time}\end{matrix} + \begin{matrix}\text{Stop}\\ \text{Time}\end{matrix} + \begin{matrix}\text{Maintenance}\\ \text{Time}\end{matrix}}\right].$$

With 8760 hours in a year, this becomes

$$U = 8760\ C_f \Big/ \left[\frac{t_s}{t_F} + R_M + 1\right]$$

where,

	Subsonic	HST	BGT
t_s = stop time per flight, (turn-around), hr	0.75	0.75	3.0
t_F = flight time, hr	4.15	2.0	1.5
R_M = maintenance hours per flight hours	0.7	1.5	4.0
C_f = factor (see below)	0.9	0.85	0.75

Based on the values given above for the terms in the equation, we have

Utilization = 4285 hrs for subsonic aircraft
2732 hours for HST
973 hours for BGT

The factor C_f is intended to cover such things as scheduling problems (inability to use the vehicle all the time available), sonic boom delays, air traffic control delays, and delays due to weather.

Cost Factors

Cost of liquid hydrogen, C_H.- Typical current (1972) value for liquid hydrogen delivered to a user site is 44¢ per kilogram (20¢/lb) (reference 6). This has been projected to a value of 28.7¢ per kilogram (13¢/lb) in 1985 and to 17.6¢ per kilogram (8¢/lb) in the year 2000 (the latter per NASA CR 73226, Air Products and Chemical Co.). A value of 8¢ per pound has been used here for the BGT baseline, operating in the year 2000.

Cost of liquid oxygen, C_O.- A price of 2.64¢ per kilogram (1.2¢/lb) has been used for liquid oxygen in the BGT baseline calculation.

Mean number of flights between main engine overhaul, F_{OH}.- This term has been set at 600 flights in the baseline BGT calculations. Rationale for this value is presented in Appendix 3-A under Main Engine Maintenance.

Annual Insurance Rate, IR.- The ATA (references 2 and 3) states that aircraft insurance rates for new aircraft are typically 5 percent but drop to 2 percent in 4 to 5 years which is a typical airline industry average. 2% was used in the HST study (reference 1) and has been used in the BGT baseline calculations.

Depreciation Life, L_d.- This is the assigned depreciation period of the vehicle. 15 years is a typical value for subsonic commercial aircraft assigned depreciation periods in accordance with industry accounting practice. 10 years was used for the HST study (reference 1) and 10 years is used for the BGT baseline calculations.

Average maintenance labor rate, r_L.- An average labor rate of \$5.62 per hour has been used in the BGT calculations. The rate applies to the average for all personnel in the maintenance operation. The ATA, (reference 2) gives \$4.00 as the input value for this parameter in its formula, at 1967 dollars. This has been increased to \$5.62 at 1973 dollars by computing a 6% annual increase for 6 years. \$5.30 was used in the HST study (reference 1).

Ratio, cost of overhaul to initial cost for main engines, R_{OH}.- This term is used in the DOC formula for main engine maintenance. Rationale for selection of its value is discussed in that section of Appendix 3-A. A value of 0.15 has been used in the BGT baseline calculations.

Launch azimuth, ϕ.- This is the angle of launch of the BGT with North = 0°, East = 90°, etc. 90° has been used for the BGT baseline demonstration calculations. The effect of a westerly versus easterly launch on DOC is shown in the Sensitivity section.

Launch latitude, θ.- This is the latitude of the launch site. 0° (equatorial) has been used in the baseline BGT calculation. The effect of another value on DOC is shown in the Sensitivity section.

Cost of the BGT and its components.- Acquisition costs for the BGT and certain of its components are required for use in the DOC formulas. These costs may be developed independently by any method, or they may be estimated using the following estimating relationships which have been developed for the baseline BGT. The costs are expressed in normalized form (i.e., divided by the gross lift-off weight of the BGT, (GLOW) for use in the DOC formulas.

$$\frac{C_{BGT}}{GLOW} = \frac{C_S}{GLOW} + \frac{C_{Eq}}{GLOW} + \frac{C_{AV}}{GLOW} + \frac{C_{ME}}{GLOW} + \frac{C_{TJ}}{GLOW} + \frac{C_{TPS}}{GLOW}, \quad \$/lb.$$

where,

C_{BGT} = cost of BGT (total), \$

C_S = cost of structure, \$

C_{Eq} = cost of all equipment and subsystems not included in other terms, \$

C_{AV} = cost of avionics, \$

C_{ME} = cost of main engine set per vehicle, \$

C_{TJ} = cost of turbojet engine set per vehicle, \$

C_{TPS} = cost of thermal protection system, \$

$$\frac{C_s}{GLOW} = 330 \frac{W_S}{GLOW}, \$/lb$$

$$\frac{C_{Eq} + C_{AV}}{GLOW} = 900 \frac{W_{Eq} + W_{AV}}{GLOW}, \$/lb$$

$$\frac{C_{ME}}{GLOW} = 5300\, T_{ME}^{0.5} \times \frac{N_{ME}}{GLOW}, \$/lb$$

$$\frac{C_{TJ}}{GLOW} = 70\, T_{TJ}^{0.9} \times \frac{N_{TJ}}{GLOW}, \$/lb$$

$$\frac{C_{TPS}}{GLOW} = \frac{1.1}{GLOW} \sum_i \exp \left[56.58 - 16.292 \ln T_i + 1.279 (\ln T_i)^2\right] A_i, \$/lb$$

where,

W_S = weight of structure, lbs

W_{Eq} = weight of equipment and subsystems excluding ME, TJ, TPS & AV, lbs

W_{AV} = weight of avionics, lbs

N_{ME} = number of main engines per vehicle

N_{TJ} = number of turbojet engines per vehicle

T_{ME} = thrust of main engines (vacuum) each, lbs

T_{TJ} = thrust of turbojet engines, each, lbs

A_i = area of surface protected by TPS against temperature i, ft^2

T_i = maximum temperature of surface area A_i, degrees F

The above cost estimating relationships were developed from costs used in the Space Shuttle program (proposal period) after application of a 90% learning curve to reflect the average cost for 100 units.

The relationship for the TPS was constructed by plotting TPS materials and costs per square foot proposed in the Shuttle program and fitting the curve expressed in the CER equation to these points.

For the purposes of the baseline BGT demonstration herein, the BGT was divided into the following four areas and temperature regimes.

A_i	T_i	Cost
7,924 ft^2	2500-2800°F	\$22.2 $\bar{M}$
12,750	1500-2500	23.1
7,288	800-1500	2.8
16,770	0-800	2.3
		\$50.4 M

The costs used in the Demonstration sections for the baseline BGT based on the above cost estimating relationships are:

$$\left(\frac{C_S}{GLOW}\right) GLOW \quad - \quad \$\ 83.9\ \bar{M}$$

$$\left(\frac{C_{Eq} + C_{AV}}{GLOW}\right) GLOW \quad - \quad 67.2\ \bar{M}$$

$$\left(\frac{C_{ME}}{GLOW}\right) GLOW \quad - \quad 43.6\ \bar{M}$$

$\left(\frac{C_{TJ}}{GLOW}\right)$	GLOW	-	3.0
$\left(\frac{C_{TPS}}{GLOW}\right)$	GLOW	-	50.4
	Total		\$248.1 M

As can be seen, the cost for the TPS determined using Shuttle factors appears prohibitively large when applied to a commercial aircraft. It is very probable that this high cost would stimulate research into other TPS schemes which could be implemented at a much lower cost. In fact, some studies have already shown the possibility of reusable TPS schemes at 1/10 the cost proposed for the Shuttle system. The Shuttle program will no doubt stimulate this research and so an order of magnitude reduction in TPS can be expected.

<u>K_{TPS}, fraction of original manufacturing cost per flight for maintenance</u>.- The parameter K_{TPS} accounts for the per-mission cost of TPS maintenance. This cost is comprised of two parts: (1) replacement of TPS segments and (2) post-mission inspection. As discussed previously, the per-mission maintenance is in addition to that required for complete replacement of the TPS at the end of its useful life. For the baseline vehicle, the useful life is assumed to be 500 missions. Although there is no maintenance experience for TPS, it appears reasonable to assume that the "patching" required during the useful life would amount to no more than 20% of the original TPS cost. The post-mission inspection is limited to direct labor for non-destructive-test data interpretation at rate assumed equivalent to one-half of the per-mission TPS replacement cost. On this basis, then, the baseline value of K_{TPS} is postulated to be 0.0006.

METHOD MODULE 4

TECHNOLOGY PARAMETER EQUATIONS

METHOD MODULE 4 - TECHNOLOGY PARAMETER EQUATIONS

General

This module presents the procedures and equations required to determine the effects of changes in the selected Technology Parameters on the designated Driver Parameters. The procedures are set up in a systematic step-by-step fashion so that the results can be obtained simply and quickly. Explanatory information and the derivation of equations is presented in Appendix 4-A.

Logic

In order to establish the effects of changes in Technology Parameters on the designated Driver Parameters, it is necessary to first define the relationship between them. This can be done either analytically through explicit equations, or empirically through graphs, curve fits, etc. With the relationships established, the changes can be found by using approximate differentials (herein called "partials"). The equations finally derived apply to all vehicles of interest to the hypersonic technology planner. The constants are adjusted for each defined baseline vehicle.

The Driver Parameters used in this module are listed in Table 4-I while the associated Technology Parameters are listed in Table 4-II. The expressions relating Driver Parameters to Technology Parameters are presented in the Appendix 4-A. The first Driver, airframe weight fraction, $W_{AF}/GLOW$, has been expanded into five elements as shown in the table. Of these five, the first two, fuselage weight and wing weight, contribute the major part of the airframe weight. These elements have been described in terms of both the material properties and design factors listed in Table 4-II to allow the user maximum flexibility in determining technology effects. The remaining elements are treated in a more simplified manner since they contribute relatively little to the airframe weight and are not as sensitive to technology changes.

The second Driver Parameter listed is the average thermal protection system weight per unit area. This parameter is a function of the flight conditions, the baseline vehicle characteristics and the thermal protection system properties and design. No Technology Parameters have been defined for this Driver so projections will be made of changes in the total unit weight. This approach is simpler and also has more physical significance than a combination of operational and material properties.

TABLE 4-I.- DRIVER PARAMETERS

a) $W_{AF}/GLOW$	-	airframe weight fraction which includes the following elements:
$\frac{W_F}{GLOW}$	-	fuselage weight fraction
$\frac{W_W}{GLOW}$	-	wing weight fraction
$\frac{W_E}{GLOW}$	-	horizontal and vertical surfaces weight fraction
$\frac{W_{PS}}{GLOW}$	-	propellant system weight fraction
$\frac{W_{sys}}{GLOW}$	-	other airframe systems as landing gear, power, hydraulics, etc.
b) $\frac{\bar{W}_{TPS}}{A}$	-	average thermal protection system weight per unit area
c) L_{TPS}	-	thermal protection system life (flights)
d) $\frac{W_{ME}}{T_{ME}}$	-	main engine weight-to-sea-level thrust ratio
e) I_{SP}	-	rocket engine vacuum specific impulse
f) (L/D)	-	cruise lift-to-drag ratio

TABLE 4-II.- TECHNOLOGY PARAMETERS

Aerodynamics	
C_{D_o}	zero-lift drag coefficient
$C_{D_i}/C_L{}^2$	induced drag factor
Aggregate materials properties	
FMP	fuselage material properties
WMP	wing matèrial properties
Airframe design	
$F_{W,B}$	design factor for wing structure designed by buckling criteria (= 1.00 for baseline)
$F_{W,C}$	design factor for wing structure designed by crippling criteria (= 1.00 for baseline)
$F_{W,S}$	design factor for wing structure designed by stiffness criteria (= 1.00 for baseline)
$F_{W,Y}$	design factor for wing structure designed by yield criteria (= 1.00 for baseline)
$F_{W,F}$	design factor for wing structure not designed by primary loads
$F_{F,B}$	design factor for fuselage structure designed by buckling criteria (= 1.00 for baseline)
$F_{F,C}$	design factor for fuselage structure designed by crippling criteria (= 1.00 for baseline)
$F_{F,S}$	design factor for fuselage structure designed by stiffness criteria (= 1.00 for baseline)

TABLE 4-II.- TECHNOLOGY PARAMETERS - Concluded

$F_{F,Y}$	design factor for fuselage structure designed by yield criteria (= 1.00 for baseline)
$F_{F,F}$	design factor for fuselage structure not designed by primary loads
F_E	design factor for empennage weight (= 1.00 for baseline)
F_P	design factor for propellant system weight (= 1.00 for baseline)

The third Driver, Thermal Protection System Life, L_{TPS}, is handled in the same way as the unit weight. This parameter is a function of design criteria, environment, materials, etc. and is difficult to quantitatively relate to technology parameters. Once again, projections will be made of changes of this parameter itself.

The fourth and fifth Driver Parameters are rocket engine parameters and are already technology oriented.

The last Driver Parameter shown is the cruise lift-to-drag ratio which has been related to the zero lift drag coefficient and an induced drag factor in Appendix 4-A. All the relationships have been reduced to approximate partials which respect to the appropriate Technology Parameters to obtain the final forms used in the module. With the final equations available, the baseline vehicle characteristics are now inserted and for given percentage changes in the Technology Parameters, the corresponding changes in the Driver Parameters are computed. This process is illustrated in the last section of this module wherein the baseline vehicle characteristics developed in the Baseline Vehicle Method Module are used to compute numerical values of the final equations.

Input Data

The input data required to utilize this module is shown in Table 4-III and includes values of the baseline vehicle parameters. The final equations to be used are given in the next section. The input data is taken from Tables 2-III and 2-IV.

Procedures

This section contains the step-by-step procedures to be followed in order to establish the relationships between changes in Technology Parameters and the corresponding changes in the Driver Parameters. The use of these procedures will be illustrated later in the section entitled "Demonstration."

Vehicle Parameters.- The first step in the procedure requires the evaluation of the parameters listed in Table 4-III, Baseline Vehicle Parameters - Required Input for Module 4. The airframe weight, wing weight, fuselage weight, horizontal and vertical surface weight and propellant system weight are found from the output of the Baseline BGT Definition Module.

TABLE 4-III.- BASELINE VEHICLE PARAMETERS - REQUIRED INPUT FOR MODULE 4

Airframe Weight Parameters		
$\frac{W_{Misc}}{W_{AF}}$	-	ratio of miscellaneous systems weight to total airframe weight (i.e., landing gear, power, etc.)
$\frac{W_F}{W_{AF}}$	-	ratio of fuselage weight to total airframe weight
$\frac{W_W}{W_{AF}}$	-	ratio of wing weight to total airframe weight
$\frac{W_E}{W_{AF}}$	-	ratio of horizontal and vertical surface weights to total airframe weight
$\frac{W_{PS}}{W_{AF}}$	-	ratio of propellant system weight to total airframe weight
Lift-to-Drag Ratio Parameters		
C_D	-	total vehicle glide drag coefficient
C_{D_o}	-	zero-lift glide drag coefficient
C_{D_i}/C_L^2	-	glide induced drag factor

Technology Parameter Partials.- In order to simplify the computation procedure, Table 4-IV has been prepared which lists the expressions to be used to determine the values of the Technology Parameter Partials. The expressions given in Table 4-IV are developed in Appendix 4-A. The computation procedure then simply entails entering Table 4-IV with the appropriate weight fraction obtained in the previous step (vehicle parameters) and entering the numerical value in the worksheet, Table 4-IV.

The data required to complete Table 4-IV consists of two parts, the first is input data from Table 4-III and includes the baseline vehicle weight fractions. The second part requires the evaluation of the fractions of the fuselage and wing weight designed by buckling, crippling, yield and stiffness criteria. These fractions are then applied only to that portion of the fuselage and wing weight not included in the fixed weight. The fixed weight is the weight of all elements not designed by primary loads. The fractions to be used are given in Table 4-V which were adapted from the data in reference 1. In order to use this data, the ratio of fuselage fixed weight to total fuselage weight and wing fixed weight to total wing weight must be known. The analyst has the option of using any value he may desire but if these values are not available, then the following are recommended:

$$\frac{W_{F,F}}{W_F} = 0.67 \qquad \frac{W_{W,F}}{W_W} = 0.4$$

Using these values then, we get

$$\frac{W_F'}{W_{AF}} = 0.33 \ \frac{W_F}{W_{AF}} ; \qquad \frac{W_W'}{W_{AF}} = 0.6 \ \frac{W_W}{W_{AF}}$$

These are the values needed in the expressions given in Table 4-IV.

Output Data

The output data of this module are all contained in the worksheet, Table 4-IV, and consist of the numerical values of the ratios. These values are required input data for the Results and Analyses Method Module 6.

TABLE 4-IV.- TECHNOLOGY PARAMETER PARTIALS - REQUIRED OUTPUT FROM MODULE 4

Technology Parameter	Driver Parameter	$\dfrac{\Delta\text{Driver}/\text{Driver}}{\Delta\text{Tech. Parameter}/\text{Tech. Parameter}}$ = Technology Parameter Partial	Value
C_{D_o}	L/D	$-\ C_{D_o}/C_D$	
C_{D_i}/C_L^2	L/D	$-\dfrac{C_D-C_{D_o}}{C_D}$	
$F_{W,B}$	$\dfrac{W_{AF}}{GLOW}$	$-\left(\dfrac{W'_W}{W_{AF}}\right)\left\{\dfrac{W_{W,B}}{W'_W}\right\}$	
$F_{W,C}$	"	$-\left(\dfrac{W'_W}{W_{AF}}\right)\left\{\dfrac{W_{W,C}}{W'_W}\right\}$	
$F_{W,S}$	"	$-\left(\dfrac{W'_W}{W_{AF}}\right)\left\{\dfrac{W_{W,S}}{W'_W}\right\}$	
$F_{W,Y}$	"	$-\left(\dfrac{W'_W}{W_{AF}}\right)\left\{\dfrac{W_{W,Y}}{W'_W}\right\}$	
$F_{W,F}$	"	$-\ \dfrac{W_{W,F}}{W_{A,F}}$	
$F_{F,B}$	"	$-\left(\dfrac{W'_F}{W_{AF}}\right)\left\{\dfrac{W_{F,B}}{W'_F}\right\}$	
$F_{F,C}$	"	$-\left(\dfrac{W'_F}{W_{AF}}\right)\left\{\dfrac{W_{F,C}}{W'_F}\right\}$	

TABLE 4-IV.- TECHNOLOGY PARAMETER PARTIALS - REQUIRED OUTPUT FROM MODULE 4 - Concluded

Technology Parameter	Driver Parameter	$\dfrac{\Delta\text{Driver}/\text{Driver}}{\Delta\text{Tech. Parameter}/\text{Tech. Parameter}}$ = Technology Parameter Partial	Value
$F_{F,S}$	$\dfrac{W_{AF}}{GLOW}$	$-\left(\dfrac{W'_F}{W_{AF}}\right)\left\{\dfrac{W_{F,S}}{W'_F}\right\}$	
$F_{F,Y}$	"	$-\left(\dfrac{W'_F}{W_{AF}}\right)\left\{\dfrac{W_{F,Y}}{W'_F}\right\}$	
$F_{F,F}$	"	$-\dfrac{W_{F,F}}{W_{AF}}$	
F_E	"	$-\left(\dfrac{W_E}{W_{AF}}\right)\Big/1+\left(\dfrac{\Delta F_E}{F_E}\right)$	
F_{PS}	"	$-\left(\dfrac{W_{PS}}{W_{AF}}\right)\Big/1+\left(\dfrac{\Delta F_{PS}}{F_{PS}}\right)$	
WMP	"	$\left(W_W/W_{AF}\right)$	
FMP	"	$\left(W_F/W_{AF}\right)$	

Note that in the above equations,

$$\frac{W'_F}{W_{AF}} = \frac{W_F}{W_{AF}}\left(1 - \frac{W_{F,Fixed}}{W_F}\right)$$

$$\frac{W'_W}{W_{AF}} = \frac{W_W}{W_{AF}}\left(1 - \frac{W_{W,Fixed}}{W_W}\right)$$

TABLE 4-V.- APPROXIMATE WEIGHT RATIOS FOR PRIME STRUCTURAL ELEMENTS OF BOOST-GLIDE TRANSPORT AS DESIGNED BY VARIOUS CRITERIA

Design Criterion	Element, Symbol	Weight Ratio	
		Sandwich Panel Construction	Skin-Stiffened Construction
Buckling	Fuselage, $\frac{W_{F,B}}{W'_F}$	0.40	0.50
	Wing, $\frac{W_{W,B}}{W'_W}$	0.30	0.20
Crippling	Fuselage, $\frac{W_{F,C}}{W'_F}$	0.25	0.15
	Wing, $\frac{W_{W,C}}{W'_W}$	0.20	0.10
Stiffness	Fuselage, $\frac{W_{F,S}}{W'_F}$	0.05	0.05
	Wing, $\frac{W_{W,S}}{W'_W}$	0.10	0.10
Yield	Fuselage, $\frac{W_{F,Y}}{W'_F}$	0.30	0.30
	Wing, $\frac{W_{W,Y}}{W'_W}$	0.40	0.60

Note that these percentages apply to the total wing or fuselage weight minus the wing or fuselage fixed weight. In the above,

$W'_F = W_F - W_{F,F}$ (total fuselage weight - fixed fuselage weight)

$W'_W = W_W - W_{W,F}$ (total wing weight - fixed wing wing)

DEMONSTRATION

Introduction

This section of the module presents a numerical example of the procedures and equations presented earlier, utilizing the baseline vehicle described in Module 2 of this report, Baseline BGT Definition. The example matches identically the instructions given in the earlier section entitled "Procedures" and is developed in a step-by-step fashion.

Procedures

Vehicle Parameters.- The first step requires the input of the baseline vehicle parameters listed earlier in Table 4-III. These values are obtained from the output of the Baseline BGT Definition Module (reference Tables 2-VII and 2-VIII) and are summarized in Table 4-VI.

Technology Parameter Partials.- With the baseline vehicle parameters established, we now go directly to Table 4-VII (which is simply a reproduced copy of Table 4-IV) and enter in Table 4-VII the values obtained by solving equations using the values from Tables 4-V and 4-VI. For this demonstration, we will take:

$$\frac{W_{F,F}}{W_F} = 0.67 \quad \text{and} \quad \frac{W_{W,F}}{W_W} = 0.4 \quad \text{and assume a skin stiffened structure}$$

This gives the following:

$$\frac{W_F'}{W_{AF}} = 0.33 \frac{W_F}{W_{AF}} = (0.33) \quad (0.337) = 0.112$$

$$\frac{W_W'}{W_{AF}} = (0.6) \frac{W_W}{W_{AF}} = (0.6) \quad (0.111) = 0.067$$

The output data is shown in Table 4-VII.

TABLE 4-VI.- BASELINE VEHICLE PARAMETERS - DEMONSTRATION DATA INPUT FOR MODULE 4 (Reference Table 4-III)

Airframe Weight Parameters

$\frac{W_F}{W_{AF}} = 0.337$

$\frac{W_W}{W_{AF}} = 0.111$

$\frac{W_E}{W_{AF}} = 0.035$

$\frac{W_{Misc}}{W_{AF}} = 0.195$

$\frac{W_{PS}}{W_{AF}} = 0.360$

Lift-to-Drag Ratio Parameters

$C_D = 0.044$

$C_{D_i}/C_L^2 = 1.62$

$C_{D_o} = 0.015$

TABLE 4-VII.- TECHNOLOGY PARAMETER PARTIALS - DEMONSTRATION DATA OUTPUT FROM MODULE 4 (Reference Table 4-IV)

Technology Parameter	Driver Parameter	$\dfrac{\Delta \text{Driver}/\text{Driver}}{\Delta \text{Tech. Parameter}/\text{Tech. Parameter}}$ = Technology Parameter Partial	Value
C_{D_o}	L/D	$-\ C_{D_o}/C_D$	-0.338
$C_{D_i}/C_L{}^2$	L/D	$-\ \dfrac{C_D - C_{D_o}}{C_D}$	-0.661
$F_{W,B}$	$\dfrac{W_{AF}}{GLOW}$	$-\ \left(\dfrac{W_W'}{W_{AF}}\right)\left\{\dfrac{W_{W,B}}{W_W'}\right\}$	-0.013
$F_{W,C}$	"	$-\ \left(\dfrac{W_W'}{W_{AF}}\right)\left\{\dfrac{W_{W,C}}{W_W'}\right\}$	-0.007
$F_{W,S}$	"	$-\ \left(\dfrac{W_W'}{W_{AF}}\right)\left\{\dfrac{W_{W,S}}{W_W'}\right\}$	-0.007
$F_{W,Y}$	"	$-\ \left(\dfrac{W_W'}{W_{AF}}\right)\left\{\dfrac{W_{W,Y}}{W_W'}\right\}$	-0.040
$F_{W,F}$	"	$-\ \dfrac{W_{W,F}}{W_{A,F}}$	-0.044
$F_{F,B}$	"	$-\ \left(\dfrac{W_F'}{W_{AF}}\right)\left\{\dfrac{W_{F,B}}{W_F'}\right\}$	-0.056
$F_{F,C}$	"	$-\ \left(\dfrac{W_F'}{W_{AF}}\right)\left\{\dfrac{W_{F,C}}{W_F'}\right\}$	-0.011

TABLE 4-VII.- TECHNOLOGY PARAMETER PARTIALS - DEMONSTRATION DATA OUTPUT FROM MODULE 4 (Reference Table 4-IV) - Concluded

Technology Parameter	Driver Parameter	$\dfrac{\Delta\text{Driver}/\text{Driver}}{\Delta\text{Tech. Parameter}/\text{Tech. Parameter}}$ = Technology Parameter Partial	Value
$F_{F,S}$	$\dfrac{W_{AF}}{GLOW}$	$-\left(\dfrac{W_F'}{W_{AF}}\right)\left\{\dfrac{W_{F,S}}{W_F'}\right\}$	-0.006
$F_{F,Y}$	"	$-\left(\dfrac{W_F'}{W_{AF}}\right)\left\{\dfrac{W_{F,Y}}{W_F'}\right\}$	-0.034
$F_{F,F}$	"	$-\dfrac{W_{F,F}}{W_{AF}}$	-0.226
F_E	"	$-\left(\dfrac{W_E}{W_{AF}}\right)\Big/ 1+\left(\dfrac{\Delta F_E}{F_E}\right)$	-0.032
F_{PS}	"	$-\left(\dfrac{W_{PS}}{W_{AF}}\right)\Big/ 1+\left(\dfrac{\Delta F_{PS}}{F_{PS}}\right)$	-0.327
WMP	"	$\left(W_W/W_{AF}\right)$	0.111
FMP	"	$\left(W_F/W_{AF}\right)$	0.337

Note that in the above equations,

$$\frac{W_F'}{W_{AF}} = \frac{W_F}{W_{AF}}\left(1 - \frac{W_{F,Fixed}}{W_F}\right)$$

$$\frac{W_W'}{W_{AF}} = \frac{W_W}{W_{AF}}\left(1 - \frac{W_{W,Fixed}}{W_W}\right)$$

REFERENCE

1. Taylor, Robert J., "High Temperature Airframe Weight Estimation," Society of Aeronautical Weight Engineers Technical Report No. 479, May 1965.

APPENDIX 4-A

TECHNOLOGY PARAMETER EQUATIONS

Introduction

Expressions for each of the Driver Parameters previously listed in Table 4-I are presented in the Appendix in terms of the Technology Parameters previously listed in Table 4-II. Each expression is then analytically or numerically differentiated to obtain a relationship between changes in Technology Parameters and corresponding changes in the Driver Parameters. Finally, expressions for the ratios of the percentage changes in the Driver Parameters to the percentage changes in the Technology Parameters are formulated and are used to determine the required numerical values previously given in Table 4-IV. Each Driver Parameter is treated in turn in the following sections.

Airframe Weight Fraction.- The airframe weight fraction, $W_{AF}/GLOW$, is broken into five components as shown below.

1) W_F/W_{AF} - Fuselage weight to total airframe weight

2) W_W/W_{AF} - Wing weight to total airframe weight

3) W_E/W_{AF} - Empennage weight to total airframe weight

4) W_{PS}/W_{AF} - Propellant system weight to total airframe weight

5) W_{Misc}/W_{AF} - Miscellaneous systems weight to total airframe weight

The fractional change in airframe weight fraction for a given change in any of the above five parameters is given by:

$$\frac{\Delta W_{AF}}{W_{AF}} = \left(\frac{\Delta W_i}{W_i}\right) \left(\frac{W_i}{W_{AF}}\right)$$

where i = F, W, E, PS or Misc

Each of these components can now be expressed in terms of the Technology Parameters listed earlier in Table 4-II.

Fuselage weight: The fuselage is designed by a combination of buckling, crippling, yield and stifness criteria and so the fuselage weight may be expressed as:

$$W_F = W_{F,B} + W_{F,C} + W_{F,Y} + W_{F,S} + W_{F,F}$$

where,

$W_{F,B}$ is the weight of the fuselage required to meet buckling criteria,

$W_{F,C}$ is the fuselage weight required to meet crippling criteria, etc.

This expression can be rewritten as:

$$\frac{W_F}{W_{AF}} = \frac{W'_F}{W_{AF}} \left[\frac{W_{F,B}}{W_F'} + \frac{W_{F,C}}{W_F'} + \frac{W_{F,Y}}{W_F'} + \frac{W_{F,S}}{W_F'} \right] + \frac{W_{F,F}}{W_{AF}}$$

where,

$\frac{W_F'}{W_{AF}}$ is the total fuselage weight minus the fixed fuselage weight divided by the airframe weight and the ratios in brackets represent the fractions of this weight designed by the various criteria.

The final term,

$\frac{W_{F,F}}{W_{AF}}$ is the fuselage fixed weight divided by the airframe weight.

For our purposes, the fuselage fixed weight is taken to be 2/3 of the total fuselage weight, i.e.,

$$\frac{W_{F,F}}{W_F} = 2/3; \quad \frac{W'_F}{W_F} = 1/3$$

Expressions for each of the weight elements in the above equation can now be derived as shown in Reference 1. For example, for the buckling criteria, the critical stress level, f_{CR}, for a panel of length (a), width (b), and thickness (t) subject to flat-plate buckling is:

$$f_{CR} = KE \left(\frac{t}{b}\right)^2$$

where K = buckling coefficient and E = Young's modulus.

The maximum load (P) carried by this plate is:

$$P = f_{CR}\ bt$$

and the theoretical weight of the plate is:

$$W = abt\rho$$

Combining these equations and substituting for f_{CR} we obtain:

$$W = \rho_1 \frac{K_B}{E^{0.333}}$$

where,

$$K_B = ab \left(\frac{Pb}{K}\right)^{1/3}$$

The factor K_B does not vary with material properties.

A "Design Factor," F, is now introduced into the equation to account for possible improvements in manufacturing techniques, analysis methods, etc. This factor would have the value 1.0 for the baseline and would increase for improved design techniques. The final equation then is:

<u>Buckling</u> $$W_{F,B} = \left[\frac{\rho_F\ K_{F,B}}{F_{F,B}\ E_F^{0.333}}\right]$$

Similar reasoning leads to the following equations:

$$\underline{\text{Crippling}} \qquad W_{F,C} = \left[\frac{\rho_F\, K_{F,C}}{F_{F,C}\, E_F^{\,0.225}\, f_{cy_F}^{\,0.325}}\right]$$

$$\underline{\text{Yield}} \qquad W_{F,Y} = \left[\frac{\rho_F\, K_{F,Y}}{F_{F,Y}\, f_{cy_F}}\right]$$

$$\underline{\text{Stiffness}} \qquad W_{F,S} = \left[\frac{\rho_F\, K_{F,S}}{E_{F,S}\, E_F}\right]$$

$$\underline{\text{Fixed Weight}} \qquad W_{F,F} = \left[\frac{\rho_F\, K_{F,F}}{F_{F,F}}\right]$$

A separate design factor is used for each portion of the fuselage so that improvements affecting only the portion of the fuselage designed by one of the four criteria can be taken into account without affecting the remaining weight.

It should be recognized that the three material Technology Parameters (E, f_{cy}, ρ) are strongly interrelated and should be treated together as aggregate material Technology Parameters for the fuselage (FMP) and for the wing (WMP).

The "driver partial" with variations in all three material parameters is defined by

$$\frac{\Delta W_F}{W_F} = \frac{(\rho_F+\Delta\rho_F)}{W_F}\left[\frac{K_{F,B}}{F_{F,B}(E_F+\Delta E_F)^{0.333}} + \frac{K_{F,C}}{F_{F,C}(E_F+\Delta E_F)^{0.225}(f_{cy}+\Delta f_{cy})^{0.325}} + \frac{K_{FF}}{F_F} + \frac{K_{F,Y}}{F_{F,Y}(f_{cy}+\Delta f_{cy})} + \frac{K_{F,S}}{F_{F,S}(E_F+\Delta E_F)}\right] - 1$$

Since the parameter changes are small, then

$$\frac{1}{(TP+\Delta TP)^b} \approx \frac{1 - b\left(\frac{\Delta TP}{TP}\right)}{TP^b}$$

Substituting this approximation and the previously defined weight components into the "driver partial" equation, we obtain the following:

$$\left(\frac{\Delta W_F}{W_F}\right)_{FMP} = \frac{\Delta FMP}{FMP}$$

where,

$$\frac{\Delta FMP}{FMP} = \left(\frac{\Delta\rho_F}{\rho_F}\right)\left(1 - \frac{W_{FF}}{W_F}\right) - \left(1 + \frac{\Delta\rho_F}{\rho_F}\right)\left[\left(\frac{\Delta E_F}{E_F}\right)\left\{.333\left(\frac{W_{F,B}}{W_F}\right) + .225\left(\frac{W_{F,C}}{W_F}\right) + \left(\frac{W_{F,S}}{W_F}\right)\right\} + \left(\frac{\Delta f_{cy_F}}{f_{cy_F}}\right)\left\{.325\left(\frac{W_{F,C}}{W_F}\right) + \left(\frac{W_{F,Y}}{W_F}\right)\right\}\right]$$

The design factors can be varied independently and their "driver partials" can be obtained in a similar fashion; therefore,

$$\left(\frac{\Delta W_F}{W_F}\right)_{F_i} = -\frac{\Delta F_{F,i}}{F_{F,i}}\left[\frac{W_{F,i}}{W_F}\right]$$

where i = buckling, crippling, yield stiffness, and fixed weight

Finally, the change in airframe weight produced by a given change in a Technology Parameter is given by

$$\left(\frac{\Delta W_{AF}}{W_{AF}}\right)_{TP} = \left(\frac{\Delta W_F}{W_F}\right)_{TP}\left(\frac{W_F}{W_{AF}}\right)$$

We finally obtain the equations given earlier in Table 4-IV

$$\left(\frac{\Delta W_{AF}}{W_{AF}}\right)_{FMP} = \left(\frac{\Delta FMP}{FMP}\right)\left(\frac{W_F}{W_{AF}}\right)$$

and

$$\left(\frac{\Delta W_{AF}}{W_{AF}}\right)_{F_i} = -\frac{\Delta F_{F,i}}{F_{F,i}}\left(\frac{W_{F,i}}{W_F}\right)\left(\frac{W_F}{W_{AF}}\right)$$

The wing weight is determined in exactly the same way as the fuselage weight to provide

$$\left(\frac{\Delta W_{AF}}{W_{AF}}\right)_{WMP} = \left(\frac{\Delta WMP}{WMP}\right)\left(\frac{W_W}{W_{AF}}\right)$$

$$\left(\frac{\Delta W_{AF}}{W_{AF}}\right)_{F_i} = -\left(\frac{\Delta W_{F,i}}{W_{F,i}}\right)\left(\frac{W_{W,i}}{W_W}\right)$$

where

$$\frac{\Delta WMP}{WMP} = \left(\frac{\Delta \rho_W}{\rho_W}\right)\left(1 - \frac{W_{WF}}{W_W}\right) - \left(1 + \frac{\Delta \rho_W}{\rho_W}\right)\left[\left(\frac{\Delta E_W}{E_W}\right)\left\{.333\left(\frac{W_{W,B}}{W_W}\right) + .255\left(\frac{W_{W,C}}{W_W}\right) + \left(\frac{W_{W,S}}{W_W}\right)\right\} + \left(\frac{\Delta f_{cy_W}}{f_{cy_W}}\right)\left\{.325\left(\frac{W_{W,C}}{W_W}\right) + \left(\frac{W_{W,Y}}{W_W}\right)\right\}\right]$$

Horizontal and vertical surfaces: The horizontal (if any) and vertical surfaces are not a large percentage of the total airframe weight and, in general, are not as likely to be significantly affected by technology changes as the wing and fuselage. Consequently, they will be handled in a simplified manner using only one Technology Parameter, i.e., the design factor, F_E. The equation is:

$$W_E = \left(\frac{W}{A}\right)_E \left(\frac{A_E}{F_E}\right)$$

where,

$\left(\frac{W}{A}\right)_E$ is the average weight per unit area of the surfaces, and

A_E is the total planform area of the surfaces.

The change in surface weight caused by a change in design factor is

$$\frac{\Delta W_E}{W_E} = \left(\frac{\Delta W_E}{\Delta F}\right)\left(\frac{\Delta F}{F}\right)\left(\frac{F}{W_E}\right)$$

or

$$\frac{\Delta W_E}{W_E} = \frac{\left(\frac{\Delta F}{F}\right)}{1 + \left(\frac{\Delta F}{F}\right)}$$

The final equation then is:

$$\frac{\Delta W_{AF}}{W_{AF}} = - \frac{\left(\frac{\Delta F_E}{F_E}\right)}{1 + \left(\frac{\Delta F_E}{F_E}\right)} \left(\frac{W_E}{W_{AF}}\right)$$

Propellant system weight: The propellant system weight includes the tanks and pressurization system. It is assumed that this weight can be given as a percentage of the total fuel weight, as:

$$W_{PS} = \left(\frac{W}{W_{f_T}}\right)_{PS} \left(\frac{W_{f_T}}{F_{PS}}\right)$$

where,

$\left(\frac{W}{W_{f_T}}\right)_{PS}$ is the weight per unit fuel weight, and

F_{PS} is a design factor.

The final equation is:

$$\frac{\Delta W_{AF}}{W_{AF}} = \frac{\left(\frac{\Delta F_{PS}}{F_{PS}}\right)}{1 + \left(\frac{\Delta F_{PS}}{F_{PS}}\right)} \left(\frac{W_{PS}}{W_{AF}}\right)$$

Miscellaneous systems weight: This category includes landing gear, power, power distribution, hydraulics and all other airframe subsystems not included elsewhere. For this study, it is assumed that the miscellaneous systems weight is a constant.

Lift-to-Drag Ratio.- The vehicle glide L/D can be written as,

$$L/D = \frac{C_L}{C_D}$$

where $C_D = C_{D_o} + C_{D_i}$

C_{D_o} = zero lift drag coefficient and

C_{D_i} is the induced drag coefficient

The induced drag coefficient can be written as

$C_{D_i} = \left(\frac{C_{D_i}}{C_L{}^2}\right) C_L{}^2$ where $\frac{C_{D_i}}{C_L{}^2}$ is the induced drag factor. Both C_{D_o} and $C_{D_i}/C_L{}^2$ are taken as Technology Parameters. To find the change in L/D for a given change in these parameters we use :

$$\frac{\Delta L/D}{L/D} = \left(\frac{\sigma L/D}{\sigma TP}\right)\left(\frac{\Delta TP}{TP}\right)\left(\frac{TP}{L/D}\right)$$

Zero-lift drag coefficient: The partial derivative of L/D with C_{D_o} is given by:

$$\frac{\sigma L/D}{\sigma C_{D_o}} = \frac{-\,C_L}{\left(C_{D_o} + \frac{C_{D_i}}{C_L{}^2}\,C_L{}^2\right)^2}$$

The change in L/D then is given by:

$$\frac{\Delta L/D}{L/D} = \frac{-\,C_L}{\left(C_{D_o} + \frac{C_{D_i}}{C_L{}^2}\,C_L{}^2\right)^2}\;\frac{\left(\frac{C_{D_o}}{C_L}\right)}{\left(C_{D_o} + \frac{C_{D_i}}{C_L{}^2}\,C_L{}^2\right)}\;\left(\frac{\Delta C_{D_o}}{C_{D_o}}\right)$$

or

$$\frac{\Delta L/D}{L/D} = - \frac{C_{D_o}}{C_D} \left(\frac{\Delta C_{D_o}}{C_{D_o}} \right)$$

Induced drag factor: The change in L/D for a change in the induced drag factor is found in exactly the same way as done above:

$$\frac{\Delta L/D}{L/D} = \frac{\left(\frac{C_{D_i}}{C_L{}^2} \right)}{C_L{}^2 \; C_D} \left(\frac{\Delta C_{D_i}/C_L{}^2}{C_{D_i}/C_L{}^2} \right) = - \frac{\left(C_D - C_{D_o} \right)}{C_D}$$

METHOD MODULE 5

TECHNOLOGY PROJECTIONS

METHOD MODULE 5 - TECHNOLOGY PROJECTION METHODOLOGY

Logic

The function of the subject methodology is to provide estimates of the potential technology improvements which could impact the operating cost of a boost-glide transport (BGT).

The estimates of the technology improvements are to be made by specialists in the affected technology areas (e.g., aerodynamics). The estimates may be derived by a judgmental process, but the rationale for the judgment is to be documented. The rationale will include such considerations as the technology incorporated into the baseline aircraft, historical trends, fundamental physical limits, and the specialists' conception of future developments to the end of the century.

To promote consistency across the range of technology projections, the specialists will be provided a "Technological Scenario." The scenario will present a framework of perspectives and conditions within which the BGT technological developments may be assumed to unfold. An example of a Technological Scenario is given in the Demonstration section of this module.

The specialists are also to be provided the results of Method Module 2.- Baseline BGT Definition. That module generates a comprehensive understanding of the baseline BGT, its technology state-of-the-art, and the specific baseline values for the Technology Parameters.

The Technology Parameters listed in Table 5-I are terms expressive of the state-of-the-art within specific technology areas and which have quantitative relationships (reference Module 4.- Technology Parameter Equations) with the Drivers.

The parameters are listed within three technology areas: aerodynamics; airframe design; and materials. The aerodynamics parameters are identified for the complete airframe configuration; at the option of the user, these parameters may be subdivided into wave, friction, and interference drag for the isolated and integrated aero surfaces. The airframe design parameters, $F_{(\ )}$, and aggregate material parameters (FMP, WMP) are values affecting airframe structural weight. For the present method, the parameters apply only to the prime structure of the fuselage and wing elements of the airframe. The aggregate material parameters are synthesized terms (developed in Module 4) which reflect the resultant impact which material properties (ρ, f_{cy}, and E) have upon fuselage and wing structural weight. The purpose of these terms is to correlate the interdependent effects which advanced

TABLE 5-I.- TECHNOLOGY PARAMETERS

Aerodynamics	
C_{D_o}	zero-lift drag coefficient
C_{D_i}/C_L^2	induced drag factor
Aggregate materials properties	
FMP	fuselage material properties
WMP	wing material properties
Airframe design	
$F_{W,B}$	design factor for wing structure designed by buckling criteria (= 1.00 for baseline)
$F_{W,C}$	design factor for wing structure designed by crippling criteria (= 1.00 for baseline)
$F_{W,S}$	design factor for wing structure designed by stiffness criteria (= 1.00 for baseline)
$F_{W,Y}$	design factor for wing structure designed by yield criteria (= 1.00 for baseline)
$F_{W,F}$	design factor for wing structure not designed by primary loads
$F_{F,B}$	design factor for fuselage structure designed by buckling criteria (= 1.00 for baseline)
$F_{F,C}$	design factor for fuselage structure designed by crippling criteria (= 1.00 for baseline)
$F_{F,S}$	design factor for fuselage structure designed by stiffness criteria (= 1.00 for baseline)

TABLE 5-I.- TECHNOLOGY PARAMETERS - Concluded

$F_{F,Y}$	design factor for fuselage structure designed by yield criteria (= 1.00 for baseline)
$F_{F,F}$	design factor for fuselage structure not designed by primary loads (= 1.00 for baseline)
F_E	design factor for empennage weight (= 1.00 for baseline)
F_P	design factor for propellant system weight (= 1.00 for baseline)

materials properties would have upon weight. The design parameters are factors reflecting the state-of-the-art of analysis and manufacturing. By definition, these factors apply inversely to the weights of the airframe components and are unity for the baseline. As knowledge, techniques, and tools improve in the areas of thermal and structural analysis, material properties, and fabrication, the design factors would be expected to exceed unity.

In addition to the Technology Parameters listed in Table 5-I, projections must be made on the four Driver Parameters for which no Technology Parameters were defined. These are weight per unit area of the thermal protection system, $(W/A)_{TPS}$; the rocket engine specific impulse, I_{SP}; the rocket engine weight to thrust ratio, $(W/T)_{ME}$; and finally, the thermal protection system life, L_{TPS}, expressed in number of flights. The first three are already technology oriented and potential improvements can be projected directly. The last parameter, L_{TPS}, is not as straightforward; however, Appendix 5-A contains a suggested methodology for projecting improvements in this parameter.

With the inputs listed below, the technology specialists shall prepare their estimates of the potential improvements in the Technology Parameters and Drivers and submit their products as directed.

Input Data

The following information shall be input to this module:

<u>BGT baseline data (re: Module 2, Tables 2-III and 2-IV)</u>.-

Mission definition:

$(W_{PL},\ R_T)$

(Mission profile)

Performance characteristics :

$(L/D,\ I_{SP},\ W_{P_T}/GLOW)$

Operational characteristics:

$(t_F,\ U,\ L_d)$

Vehicle characteristics:

(Configuration; general arrangement)

($(W/S)_{GLOW}$, C_D, C_L)

(N_{TJ}, T_{TJ}, $(T/W)_{GLOW}$)

(W_{ME}, N_{ME}, T/W_{ME})

Weight characteristics:

(Summary weight statement)

Design description:

(Wing structure, materials)

(Empennage structure, materials)

(Fuselage structure, materials)

(Tankage structure, material)

(Thermal management)

(Propulsion systems installation)

(Turbojet description)

(Main engine description)

(Avionics)

(Equipment)

Technology parameters: The baseline Technology Parameters shall have been specified in the format shown in the Demonstration section (Table 5-IV) of this module.

<u>Technological scenario (re: Module 1)</u>.-

Procedures

1. The specialist shall review the input data for information relevant in his technology area(s).

2. For each Technology Parameter as listed in Table 5-I, the specialist shall forecast the potential technology improvement(s) and prepare a Technology Projection Sheet, as shown on figure 5-1. These improvements shall be projected within the framework of the Technological Scenario. They are to be summarized in Table 5-II.

In forecasting improvements in the aggregate material parameters, the individual properties (ρ, f_{cy}, E) of advanced materials shall be entered into the following expressions :

$$\frac{\Delta FMP}{FMP} =$$

$$\left(1 + \frac{\Delta\rho_F}{\rho_F}\right) \left[1 - \left(\frac{\Delta E_F}{E_F}\right)\left(0.33 \frac{W_{F,B}}{W'_F} + 0.23 \frac{W_{F,C}}{W'_F} + \frac{W_{F,S}}{W'_F}\right) - \left(\frac{\Delta f_{cy}}{f_{cy}}\right)\left(0.33 \frac{W_{F,C}}{W'_F} + \frac{W_{F,Y}}{W'_F}\right)\right] -1$$

$$\frac{\Delta WMP}{WMP} =$$

$$\left(1 + \frac{\Delta\rho_W}{\rho_W}\right) \left[1 - \left(\frac{\Delta E_W}{E_W}\right)\left(0.33 \frac{W_{W,B}}{W'_W} + 0.23 \frac{W_{W,C}}{W'_W} + \frac{W_{W,S}}{W'_W}\right) - \left(\frac{\Delta f_{cy}}{f_{cy}}\right)\left(0.33 \frac{W_{W,C}}{W'_W} + \frac{W_{W,Y}}{W'_W}\right)\right] -1$$

where the weight ratios are obtained from Table 5-III. (Note: The weight ratios shown are appropriate to the accuracy requirements of this module.

Technology Parameter: 1

Baseline Value: 2

Baseline Reference Report: 3

Technology Parameter Improvement:

Basis for Estimate	% Improvement
≈90% (Conservative)	________
≈50% (Probable)	4
≈10% (Optimistic)	________

Rationale (use additional page, as required):

5

Submitted by:

Name: ________
Mail Code: ________
Telephone: ________
Date: ________

Figure 5-1.- Sample format: Technology Projection Sheet
(See Attachment for notes of explanation)

Attachment to Figure 5-1.- Notes of explanation

1. Enter the name and symbol of the Technology Parameter, e.g., zero-lift drag coefficient, C_{D_o}, or Driver, as appropriate.

2. Enter the value from the input data.

3. Enter the document references which provide the basis for the Baseline Value.

4. At a minimum, enter the 50% confidence-level (CL) estimate as a percentage of the baseline value. The higher and lower CL estimates are desired, but not mandatory. The 50% CL estimate is considered to be as likely to be attained as it is not to be attained.

5. Enter a narrative rationale supportive of the probable estimate. The rationale may use historical trends and/or future expectations.

TABLE 5-II.- TECHNOLOGY PROJECTION SUMMARY - REQUIRED OUTPUT FROM MODULE 5

Technology Parameter, TP_i		$\Delta TP_i/TP_i$ Percent		
		10% (Optimistic)	50% (Probable)	90% (Conservative)
<u>Aerodynamics</u>				
C_{D_o}	zero-lift drag coefficient			
C_{D_i}/C_L^2	induced drag factor			
<u>Airframe design</u>				
$F_{W,B}$	design factor for wing structure designed by buckling criteria (= 1.00 for baseline)			
$F_{W,C}$	design factor for wing structure designed by crippling criteria (= 1.00 for baseline)			
$F_{W,S}$	design factor for wing structure designed by stiffness criteria (= 1.00 for baseline)			
$F_{W,Y}$	design factor for wing structure designed by yield criteria (= 1.00 for baseline)			
$F_{W,F}$	design factor for wing structure not designed by primary loads (= 1.00 for baseline)			
$F_{F,B}$	design factor for fuselage structure designed by buckling criteria (= 1.00 for baseline)			
$F_{F,C}$	design factor for fuselage structure designed by crippling criteria (= 1.00 for baseline)			

TABLE 5-II.- TECHNOLOGY PROJECTION SUMMARY - REQUIRED OUTPUT FROM MODULE 5 - Continued

Technology Parameter, TP_i		$\Delta TP_i/TP_i$ Percent 10% (Optimistic)	50% (Probable)	90% (Conservative)
$F_{F,S}$	design factor for fuselage structure designed by stiffness criteria (= 1.00 for baseline)			
$F_{F,Y}$	design factor for fuselage structure designed by yield criteria (= 1.00 for baseline)			
$F_{F,F}$	design factor for fuselage structure not designed by primary loads (= 1.00 for baseline)			
F_E	design factor for empennage weight (= 1.00 for baseline)			
F_P	design factor for propellant system weight (= 1.00 for baseline)			
<u>Aggregate materials properties</u>				
FMP	fuselage material properties			
WMP	wing material properties			
<u>Thermal Protection System (TPS)</u>				
$\left(\frac{W}{A}\right)_{TPS}$	average weight per unit area of TPS			
L_{TPS}	TPS life in number of flights			

TABLE 5-II.- TECHNOLOGY PROJECTION SUMMARY - REQUIRED OUTPUT FROM MODULE 5 - Concluded

Technology Parameter, TP_i		$\Delta TP_i/TP_i$ Percent		
		10% (Optimistic	50% (Probable)	90% (Conservative)
Propulsion				
I_{SP}	main engine vacuum specific impulse			
$\left(\frac{W}{T}\right)_{ME}$	main engine weight to sea-level thrust			

TABLE 5-III.- APPROXIMATE WEIGHT RATIOS FOR PRIME STRUCTURAL ELEMENTS OF HYPERSONIC TRANSPORT AS DESIGNED BY VARIOUS CRITERIA

Design criterion	Element, symbol	Weight Ratio	
		Sandwich panel construction	Skin-stiffened construction
Buckling	Fuselage, $\frac{W_{F,B}}{W'_F}$	0.40	0.50
	Wing, $\frac{W_{W,B}}{W'_W}$	0.30	0.20
Crippling	Fuselage, $\frac{W_{F,C}}{W'_F}$	0.25	0.15
	Wing, $\frac{W_{W,C}}{W'_W}$	0.20	0.10
Stiffness	Fuselage, $\frac{W_{F,S}}{W'_F}$	0.05	0.05
	Wing, $\frac{W_{W,S}}{W'_W}$	0.10	0.10
Yield	Fuselage, $\frac{W_{F,Y}}{W'_F}$	0.30	0.30
	Wing, $\frac{W_{W,Y}}{W'_W}$	0.40	0.60

If, however, estimates are available for the specific baseline BGT design, it is suggested they be used in lieu of Table 5-III).

3. All Technology Projection Sheets shall be collected and compiled within a summary table as shown in Table 5-II.

Output Data

The output of this module shall be Technology Projection Sheets (reference figure 5-1), corresponding to the Technology Parameters given in Table 5-I, and the Technology Projection Summary shown in Table 5-II.

DEMONSTRATION

This section provides a typical example of how the procedures of this method module are to be applied. The example given below includes data from the BGT baseline defined in Module 2 of this report. The selection of data and format responds to the preceding "Input Data" requirements.

Input Data

Summary characteristics of this baseline BGT are presented in Table 2-VIII.

Mission.- The mission of the baseline BGT is to transport payloads of 19 050 kg (42 000 lb) to destinations corresponding in range to 17 190 km (10 680 s. mi.). The BGT is to operate routinely and safely as a commercial transport aircraft over international routes.

The BGT is to have the flexibility of carrying either passengers or cargo, with payload-peculiar modifications being limited to the payload compartment and payload provisions. The basic economic analysis in Module 3 assumes a cargo payload, and direct operating costs are expressed in cents per ton-mile. The procedure for converting to cents per passenger-mile is also given in Module 3.

The flight profile for the baseline mission is shown in figure 2-2. Following vertical launch, the glide vehicle is accelerated to its maximum velocity at a main engine burnout altitude of 67 060 m (220 000 ft). The glide (and cruise) path is defined as that portion of the flight path along which the vehicle decelerates from main engine burnout conditions to a glide velocity of 366 m/sec (1200 ft/sec). The terminal segment of the flight path is that traversed during the final descent and landing approach. The ascent phase contributes about 6.4 per cent of the range, the glide (and cruise) phases cover about 93.2 per cent, and the final descent and landing approach about 0.4 per cent of the total range.

Total flight time is 1.40 hours for the baseline mission. Allowing 0.10 hours for ground-taxi after touch-down yields a total mission time of 1.5 hours.

TABLE 2-VIII.- BASELINE BGT SUMMARY CHARACTERISTICS

Mission and operations

Payload weight	19 050 kg (42 000 lb)
Payload volume	549 m^3 (19 400 ft^3)
Passenger seats	195
Total range for due-East launch	17 190 km (10 680 s. mi.)
Block time	1.5 hr
Flight cycles during depreciable life	7143

Vehicle

Aerodynamic configuration: double-delta, low-wing blended with flat underside of modified, elliptical, homothetic body; elevons plus canard for subsonic only; single vertical with split rudder/speed brake.

General arrangement: hybrid integral LH_2 multicell tank forward; LO_2 multicell tank integrated with wing carry-through and "multicell" payload compartment; propulsion section aft.

Main engines: twelve main engines improved from Shuttle Orbiter

Post-ascent engines: two Space Tug-type engines

Loiter/landing engines: four hydrogen-fueled nonaugmented turbojets

Design and structures

Wing : thermally protected aluminum alloy multispar
Vertical tail: thermally protected aluminum alloy
Fuselage: thermally protected aluminum alloy
Propellant tanks: aluminum alloy multicell tanks integrated with fuselage and carry-through in a hybrid configuration
Thermal protection system: ceramic and elastomeric reusable surface insulation; reinforced carbon-carbon in wing leading edge and body nose cap
Propulsion section: lightly-loaded external structure; large access panels; swing-out inlets for turbojet engines

Weight

Gross take-off weight	1 814 400 kg (4 000 000 lb)
Landing weight	277 610 kg (612 000 lb)
Dry weight	243 600 kg (537 000 lb)

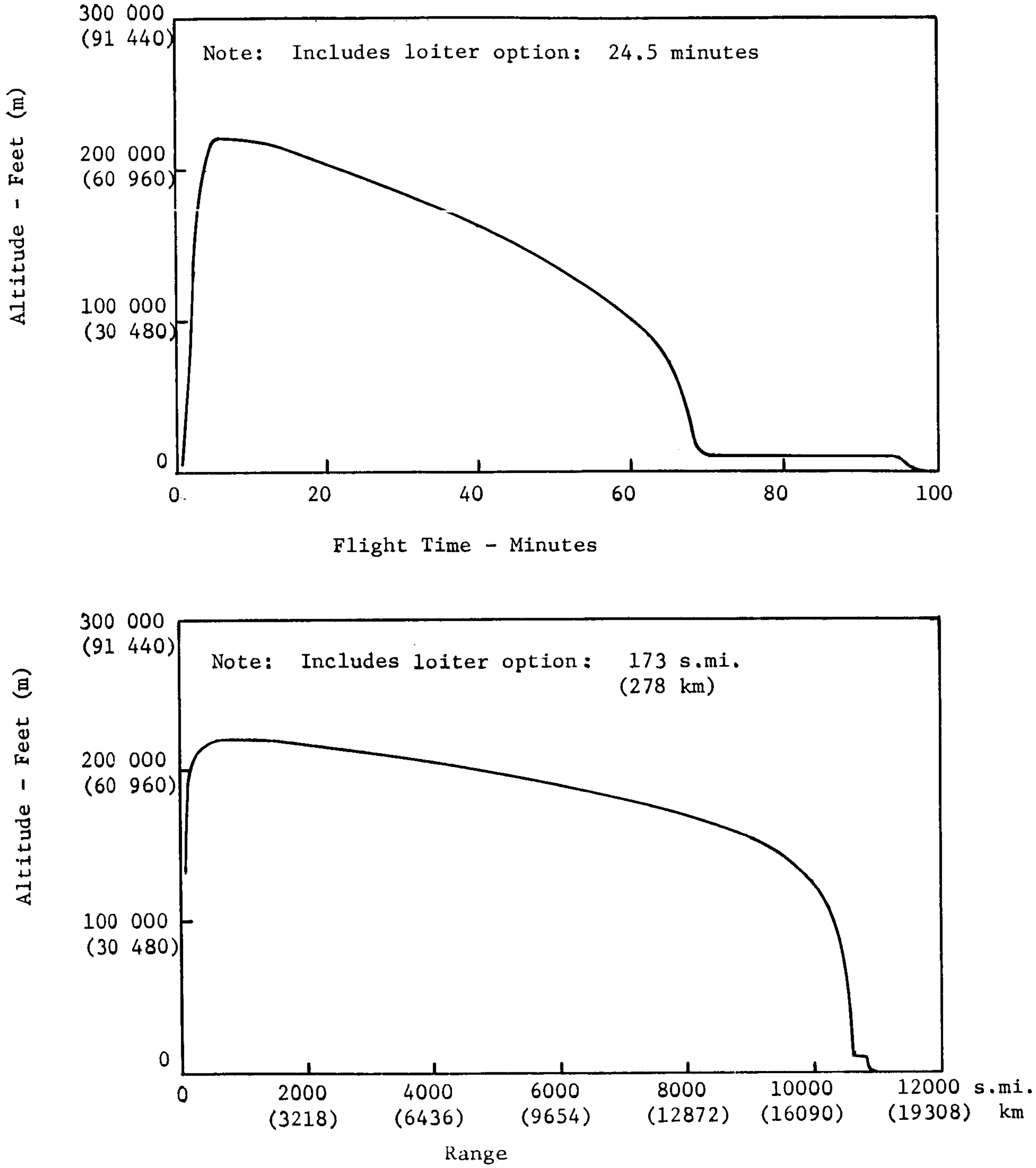

Figure 2-2.- Flight Profile

Performance.- BGT performance is summarized in the flight profile, figure 2-2, and in the confirmation of range on pages 2-18, 2-20, and 2-21. Primary input values upon which the performance is based appear in the confirmation. Other conditions and/or assumptions which contribute to the performance definition are summaried in the following listing:

Short vertical boost phase followed by programed pitchdown maneuver.

Sequential engine throttling and shutdown to hold limit acceleration to 2g.

Main engine burnout at zero flight path angle and at altitude for commencement of the glide (or cruise).

Propellant mass fraction of 0.8352 usable by main engines.

Propellant mass fraction of 0.02685 (based on W_{BO}) usable by post-ascent engines.

Hypersonic lift-drag ratio of 3.0 assumed to be constant throughout glide descent.

Subsonic lift-drag ratio of about 5.0.

Operational characteristics.- Factors which define BGT utilization are summarized in the following tabulation.

Time of flight, t_F = 1.4 hr

Block time, t_B = 1.5 hr

Average utilization, U = 1000 flight hr/yr

Depreciable life, L_d = 10 yr

Utilization during depreciable life = 10 000 flight hr
= 10 714 block hr

Non-utilization during depreciable life = 76 886 hr

Flight cycles during depreciable life = 7143

Total number of seats = 200

Number of passenger seats = 195

Average load factor = 0.60

Configuration and general arrangement.- The general arrangement of the baseline BGT is shown in figure 2-3.

Body: The baseline design employs a homothetic (constant cross-sectional shape) body. This body cross-section has been developed by NASA/LRC from a basic cross-section having an elipticity of 2.0. The combination of a flat undersurface and inward sloping side surfaces yields favorable hypersonic lift-drag characteristics and reduces heat loads on the side surfaces. A high-fineness ratio nose (0.833 times body length) contributes to the attainment of a hypersonic lift-drag ratio of 3.0. Nose camber improves hypersonic pitch trim.

Wing: The double delta wing planform was selected based on Shuttle phase C findings. Basically, the double delta (1) extends the useful angle of attack range, i.e. - postpones stall, (2) linearizes the pitching moment characteristic at low speed, (3) also reduces the shift of the aerodynamic center with Mach number, and (4) further shields the sides of the fuselage from high heating. The planform of the basic wing (neglecting the forward glove) has an aspect ratio of 2.265 and taper ratio of 0.2 as does the Shuttle. Full-span elevons are the primary aerodynamic means of developing pitch and roll control forces.

Canard surface: A canard control surface, which is stowed flush with the forward body side surface during hypersonic and supersonic flight, is deployed as a control and lift augmentation device for subsonic flight only. The canard control surface can increase elevon effectiveness by reducing the BGT stability margin when deployed. The canard also augments the elevon by providing control forces on a long moment arm in the direction of desired response.

Vertical tail: The single vertical tail arrangement is adapted from Shuttle. A split rudder provides directional stability augmentation in the supersonic flight regime and drag modulation for the subsonic flight phases, approach and landing.

Interior arrangement: The arrangement of the LH_2 and LO_2 tanks and payload compartment provides a fuselage packaging efficiency of 0.734 excluding propulsion and crew compartment. This is achieved in part by the use of multicell tanks, in part by the use of a hybrid integral tank structure and in part by the integration of the LO_2 tank with the wing carry through, and the adjacent location of the payload compartment. As shown in figure 2-2, the large LH_2 tank is of 3-cell construction; both the LO_2 tank and payload compartments utilize 5 cells. The payload compartment is located close to the vehicle center of gravity to minimize the effects of payload variations on c.g. and trim.

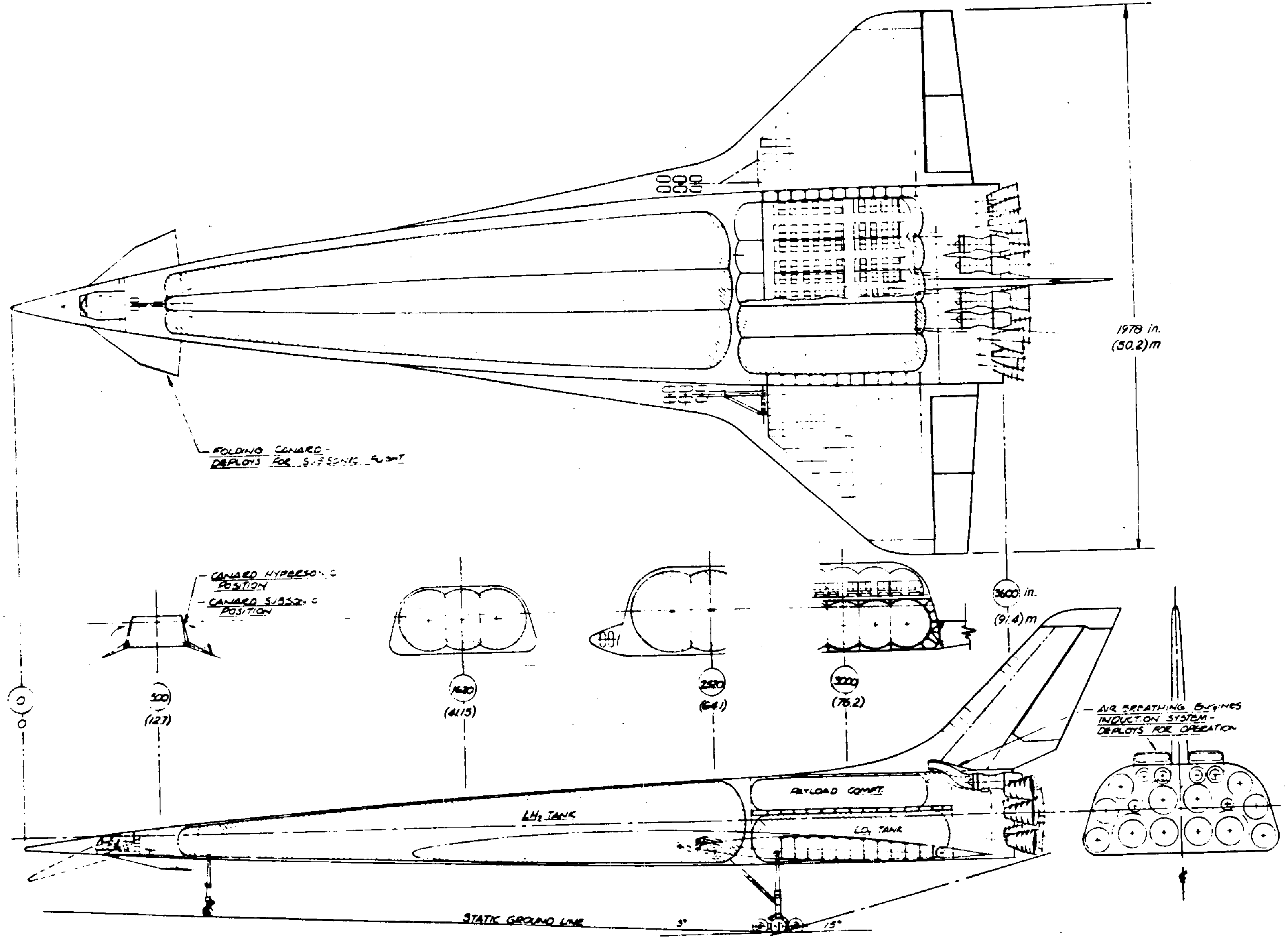

Figure 2-3.- Baseline Boost-Glide Transport

Propulsion: The BGT boost propulsion employs 12 main engines which are derived from the Shuttle orbiter main engines. Two small space tug-type engines are employed during the post-ascent period for control augmentation and range extension. Four integral hydrogen-burning airbreathers are used for idle-mode descent, final approach and landing. Sufficient fuel is carried to provide a 173 s. mi. loiter capability at the end of the mission to accommodate delays in landing or to permit the use of alternate fields. Through the modular addition of nacelle-mounted airbreathers, a self-ferry capability also is provided.

Configuration data: Selected data which summarize the geometrical characteristics of the baseline BGT are presented in Table 2-IX.

Aerodynamic characteristics.- Aerodynamic characteristics of the baseline BGT are based on a reference wing area of 1115 m^2 (12 000 ft^2). This is the planform area of the basic wing including that portion covered by the fuselage and excluding the forward delta.

For maximum range, the BGT will glide at maximum lift-drag ratio. Key summary hypersonic aerodynamic characteristics are:

$$C_{D_o} = 0.0149$$

$$C_{D_i}/{C_L}^2 = 1.62$$

$$\alpha = 10°$$

$$C_L = 0.133$$

$$C_D = 0.0436$$

$$L/D = 3.0$$

Reference wing loading at landing is 277 600 kg/1115 m^2 or 249 kg/m^2 (51 lb/ft^2). Landing speed is approximately 267 km/hr (166 s. mi./hr.).

Mass properties summary.- Estimated weights of the baseline BGT are summarized in Table 2-X. The weight estimates summarized in the table are the basis for derivation of the weight fractions for use in Module 3 and weight parameters for Module 4.

TABLE 2-IX.- BGT CONFIGURATION DATA

	SI units	English units
Body		
Length	91.4 m	300 ft
Half-width	9.14 m	30 ft
Height	8.11 m	26.6 ft
LH_2 tank volume	11 180 m^3	120 300 ft^3
LO_2 tank volume	3920 m^3	42 170 ft^3
Payload compartment volume	1800 m^3	19 400 ft^3
Fuselage total volume	7015 m^3	247 700 ft^3
Wing		
Reference area	1115 m^2	12 000 ft^2
Exposed area less fwd delta	537 m^2	5780 ft^2
Exposed area with fwd delta	610 m^2	6565 ft^2
Aspect ratio	2.265	
Taper ratio	0.20	
Root chord	36.97 m	121.3 ft
Tip chord	7.41 m	24.3 ft
Exposed root chord	26.21 m	86.0 ft
Mean aerodynamic chord	22.19 m	72.8 ft
Wing span	50.23 m	164.8 ft
Exposed structural semi-span	15.97 m	52.4 ft
Leading edge sweep	48.5°	
Trailing edge sweep	-5°	
Elevon hinge line sweep	0°	
Elevon area	108.7 m^2	1170 ft^2
Vertical tail		
Area	121.8 m^2	1311 ft^2
Root chord	13.11 m	43.0 ft
Tip chord	5.94 m	19.5 ft
Span	14.63 m	48.0 ft
Leading edge sweep	45°	
Rudder area	30.6 m^2	329 ft^2
Canard (all movable)		
Exposed area	33.4 m^2	360 ft^2

TABLE 2-X.- BGT WEIGHT SUMMARY

Item	Weight kg	Weight lb
Structure, W_S	(114 010)	(251 340)
Wing	16 440	36 240
Vertical tail	3 540	7 810
Canard	1 570	3 460
Body	50 250	110 780
Propellant tanks	38 810	85 550
Propellant tank insulation	3 400	7 500
Equipment, W_{Eq}	(33 950)	(74 840)
Post-ascent engine and system	500	1 100
Propellant system	10 680	23 540
Landing gear	9 150	20 160
Surface controls	2 350	5 170
Power and distribution	7 300	16 100
Hydraulics	2 940	6 480
Environmental control	1 030	2 260
Thermal protection system, W_{TPS}	(23 670)	(52 190)
Wing	8 930	19 680
Vertical tail	1 510	3 330
Body	13 230	29 180
Main engine and accessories, W_{ME}	(35 730)	(78 760)
Air-breathing propulsion system, W_{TJ}	(12 070)	(26 600)
Avionics	(1 860)	(4 100)
Payload provisions	(4 580)	(10 100)
Growth/uncertainty	(17 730)	(39 100)
DRY WEIGHT	(243 600)	(537 000)
Personnel	(630)	(1 400)
Payload	(19 050)	(42 000)
ABPS fuel	(7 620)	(16 800)
Residuals	(6 710)	(14 800)
LANDING WEIGHT	(277 610)	(612 000)

TABLE 2-X.- BGT WEIGHT SUMMARY - Concluded

Item	Weight	
	kg	lb
Post-ascent propulsion and supplementary ACS propellants	(7 710)	(17 000)
Glide-phase losses	(1 810)	(4 000)
BEGIN-GLIDE WEIGHT	(287 130)	(633 000)
Reserve fluids	(5 220)	(11 500)
Ascent-phase losses	(6 580)	(14 500)
Useful main engine propellants	(1 515 470)	(3 341 000)
GROSS LIFT-OFF WEIGHT	(1 814 400)	(4 000 000)

The primary structural and subsystems weights for the boost-glide transport (BGT) are estimated to be representative for the post-2000 time period. In predicting BGT weights using the current Space Shuttle Orbiter weight statement as a reference, selected weight improvements associated with this later time period are incorporated.

A major reduction in the unit weights of the primary structure relative to Shuttle conventional materials and design is potentially achievable with advance materials and composites. Therefore, the BGT unit weights for the wing, tail, moveable surfaces and body, including carry-through and thrust structure, are predicted as 25 percent less than Shuttle Orbiter unit weights.

Technology Parameters

Table 5-IV gives the baseline values for the demonstration BGT design.

Technological Scenario.- By the early 80's, the Shuttle program will have demonstrated its promised economics of launch and reuse. A highly favorable public and government reaction to the airplane-like mode of flight into space will provide support for increased traffic and additional mission applications. During the mid-80's, the Shuttle will be flying routine missions to space, and post-flight refurbishment and pre-launch readiness operations will gravitate toward airline-types of practices. Technology will be accelerated to reduce recurring and operations cost through longer-life propulsion hardware and minimum maintenance thermal protection systems.

By the early 90's, turn-arounds within several hours and automated preflight checks and countdowns will be commonplace. Additional economies will be effected by reducing the amount and unit cost of the expendable hardware. With continued improvements in materials and flight technologies, the potential of an economic single-stage-to-orbit Shuttle will be seen to be a practical goal by the late 90's. Concurrently, the potential application of the technological and operational state-of-the-art to a boost-glide transport (BGT) will receive growing acceptance by the government. By the turn-of-the-century, an advanced Shuttle will demonstrate the practicability of flying boost-glide missions to any place on the earth's surface within a 1.5 hour block time. This position will be augmented by the availability of cheap power and low-cost propellants made possible by the introduction of fusion energy systems. The military and civil transportation implications of the demonstration will create a surge of support for a go-ahead of the BGT to be operational by the second decade of the new century.

TABLE 5-IV.- TECHNOLOGY PARAMETERS

Technology Parameter		Baseline values	
		SI units	English units
Aerodynamics			
C_{D_o}	zero-lift drag coefficient	0.0149	
C_{D_i}/C_L^2	induced drag factor	1.62	
Aggregate material properties			
FMP	fuselage material properties	1.00*	
WMP	wing material properties	1.00*	
Airframe design			
$F_{W,B}$	design factor for wing structure designed by buckling criteria	1.00	
$F_{W,C}$	design factor for wing structure designed by crippling criteria	1.00	
$F_{W,S}$	design factor for wing structure designed by stiffness criteria	1.00	
$F_{W,Y}$	design factor for wing structure designed by yield criteria	1.00	
$F_{W,F}$	design factor for wing structure not designed by primary loads	1.00	
$F_{F,B}$	design factor for fuselage structure designed by buckling criteria	1.00	
$F_{F,C}$	design factor for fuselage structure designed by crippling criteria	1.00	

*The parameters FMP and WMP always have the value 1.0 for the baseline vehicle. (See Module 4 for definition).

TABLE 5-IV.- TECHNOLOGY PARAMETERS - Concluded

Technology Parameter		Baseline values SI Units	Baseline values English units
$F_{F,S}$	design factor for fuselage structure designed by stiffness criteria	1.00	
$F_{F,Y}$	design factor for fuselage structure designed by yield criteria	1.00	
$F_{F,F}$	design factor for fuselage structure not designed by primary loads	1.00	
F_E	design factor for empennage weight	1.00	
F_P	design factor for propellant system weight	1.00	
Thermal Protection System (TPS)			
$\left(\frac{W}{A}\right)_{TPS}$	average weight per unit area of thermal protection system	5.1 kg/m^2	1.09 lb/ft^2
L_{TPS}	TPS life measured in flights	500 flights	
Propulsion			
I_{SP}	main engine vacuum specific impulse	4560 $\frac{N\text{-}sec}{kg}$	465 $\frac{lb_f\text{-}sec}{lb_m}$
$\left(\frac{W}{T}\right)_{ME}$	main engine weight to sea-level thrust	0.00137 $\frac{kg}{N}$	0.01347

Output Data

Table 5-V is the summary compilation of the preliminary projections made by the method-development team at the Space Division of Rockwell International. Upper and lower confidence values are not specified; however, Method Module 6 includes means for the entire table to be filled in.

TABLE 5-V.- TECHNOLOGY PROJECTION SUMMARY - DEMONSTRATION DATA OUTPUT FROM MODULE 5 (Reference Table 5-II)

Technology Parameter, TP_i		$\Delta TP_i/TP_i$ Percent		
		10% (Optimistic)	50% (Probable)	90% (Conservative)
Aerodynamics				
C_{D_o}	zero-lift drag coefficient	-20	-10	0
C_{D_i}/C_L^2	induced drag factor	-5	-2.5	0
Airframe design				
$F_{W,B}$	design factor for wing structure designed by buckling criteria (= 1.00 for baseline)		10	
$F_{W,C}$	design factor for wing structure designed by crippling criteria (= 1.00 for baseline)		10	
$F_{W,S}$	design factor for wing structure designed by stiffness criteria (= 1.00 for baseline)		10	
$F_{W,Y}$	design factor for wing structure designed by yield criteria (= 1.00 for baseline)		10	
$F_{W,F}$	design factor for wing structure not designed by primary loads (= 1.00 for baseline)		10	
$F_{F,B}$	design factor for fuselage structure designed by buckling criteria (= 1.00 for baseline)		10	

TABLE 5-V.- TECHNOLOGY PROJECTION SUMMARY - DEMONSTRATION DATA OUTPUT FROM MODULE 5 (Reference Table 5-II) - Continued

Technology Parameter, TP_i		$\Delta TP_i/TP_i$ Percent		
		10% (Optimistic)	50% (Probable)	90% (Conservative)
$F_{F,C}$	design factor for fuselage structure designed by crippling criteria (= 1.00 for baseline)			
$F_{F,S}$	design factor for fuselage structure designed by stiffness criteria (= 1.00 for baseline)			
F $F_{F,Y}$	design factor for fuselage structure designed by yield criteria (= 1.00 for baseline)		10	
$F_{F,F}$	design factor for fuselage structure not designed by primary loads (= 1.00 for baseline)			
F_E	design factor for empennage weight (= 1.00 for baseline)			
F_P	design factor for propellant system weight (= 1.00 for baseline)			
<u>Aggregate materials properties</u>				
FMP	fuselage material properties		-10	
WMP	wing material properties		-10	

TABLE 5-V.- TECHNOLOGY PROJECTION SUMMARY - DEMONSTRATION DATA OUTPUT FROM MODULE 5 (Reference Table 5-II) - Concluded

Technology Parameter, TP_i		$\Delta TP_i/TP_i$ Percent		
		10% (Optimistic)	50% (Probable)	90% (Conservative)
Thermal Protection System, TPS				
$\left(\frac{W}{A}\right)_{TPS}$	average weight per unit area of thermal protection system		-10	
L_{TPS}	TPS life measured in flights	+1328	+1328	+614
Propulsion				
I_{SP}	main engine vacuum specific impulse	+2	0	0
$\left(\frac{W}{T}\right)_{ME}$	main engine weight to sea-level thrust		-10	

APPENDIX 5-A

PROJECTION OF THERMAL PROTECTION SYSTEM LIFE FOR THE BOOST-GLIDE TRANSPORT

The life potential of thermal protection systems for the operational version (circa 2000-2010) of a boost-glide transport (BGT) has been projected to be equivalent to the useful life of the airframe (≈ 7000 missions).

Although the TPS state-of-the-art is in its infancy, the dynamic progress of the past several years leads to an optimistic appraisal of the future potential. Development tests currently in process suggest that, by the end of 1973, silica-based TPS materials will demonstrate a 100 simulated-mission life at a peak surface temperature of 2300°F. By the end of the decade, it is postulated that technology advances might support a 1000 mission life for an equivalent environment. At the lower surface temperature of the boost-glide transport (BGT), 2100°F, the current technology could probably support a 500 mission life - corresponding to that of the BGT baseline.

The above points are illustrated in figure 5-A-1 and include a speculative extrapolation to the end of the century. On these premises, it is projected that the Driver, L_{TPS}, could approach a potential value equivalent to that of the vehicle's primary structure.

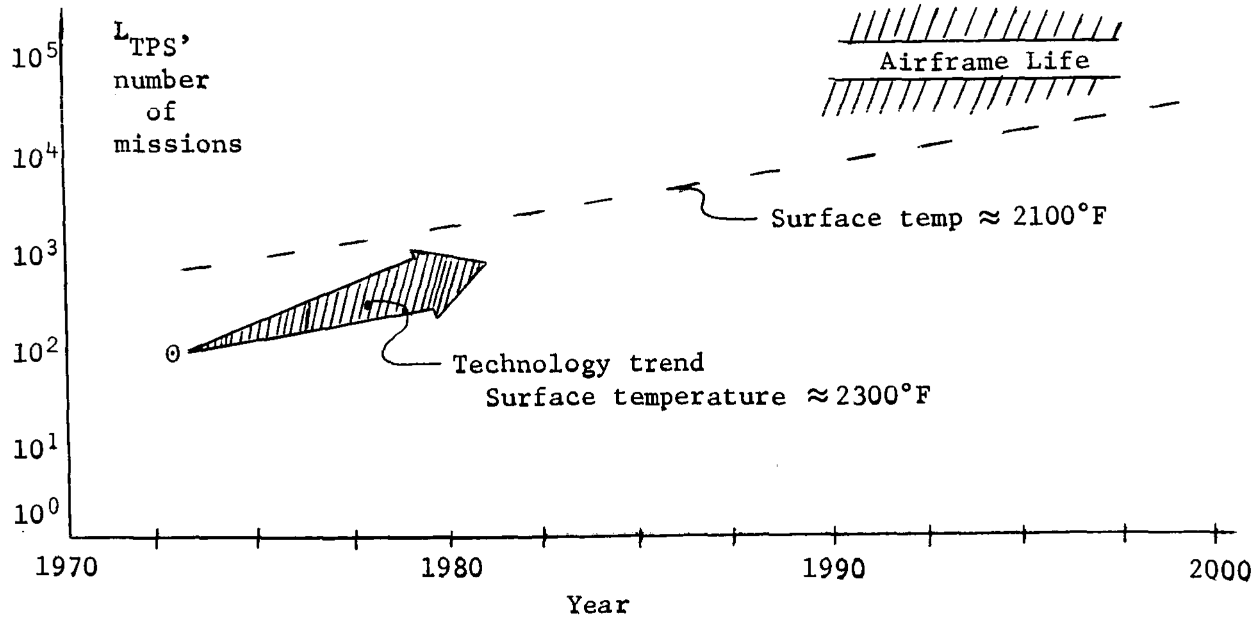

Figure 5-A-1.- Life Projection of TPS

METHOD MODULE 6

RESULTS AND ANALYSES

METHOD MODULE 6 - RESULTS AND ANALYSES

Logic

The function of this module is to collect and collate the results of the overall method, and to perform analyses to verify the validity of the results for the purpose of technology planning.

Figure 6-1 illustrates the logic flow of this module. Modules 3, 4, and 5 provide the essential inputs in data format. The results are derived by solution of the following general expression:

$$\Delta DOC_{ij} = (DOC)_{BL} \quad \times \quad \overbrace{\left(\frac{\Delta DOC/DOC}{\Delta Dr/Dr}\right)_j}^{\text{Driver "Partial"}} \quad \times \quad \overbrace{\left(\frac{\Delta Dr/Dr}{\Delta TP/TP}\right)_{ij}}^{\text{Technology Parameter "Partial"}} \quad \times \quad \overbrace{(\Delta TP/TP)_i}^{\text{Technology Projection}}$$

The Technology Projection term represents the probable improvement in the baseline Technology Parameters, as judged by the technology specialist(s). This method identified 20 ($i = 1, 2, 3 \ldots 20$) such parameters.

The Technology Parameter "partial" (obtained from Module 4) relates the change in each of 5 Drivers ($j = 1, 2 \ldots 5$) to the Technology Parameters. Since each Technology Parameter affects one, and only one Driver, there are only as many partials (20) as there are Technology Parameters.

The Driver "partial" (obtained from Module 3) relates the change in total DOC to the Drivers. This method identified 6 such partials corresponding to the 6 ($j = 1, 2 \ldots 6$) Drivers.

The baseline value of DOC is taken from Module 3 and, when multiplied by the product of the above three terms, gives the reduction in the baseline operating cost attributable to the Technology Projection, $(\Delta TP/TP)_i$. Considering that a single Technology Parameter partial is allied to one, and only one Driver partial, there are then 20 values of ΔDOC_{ij} to be determined in this module. By the way the methodology is established, the method allows revision of the Technology Projections without change to the remaining terms of the above equation.

The results are to be integrated and presented in the results summary chart illustrated in figure 6.1. The absicssa for each of the Drivers is

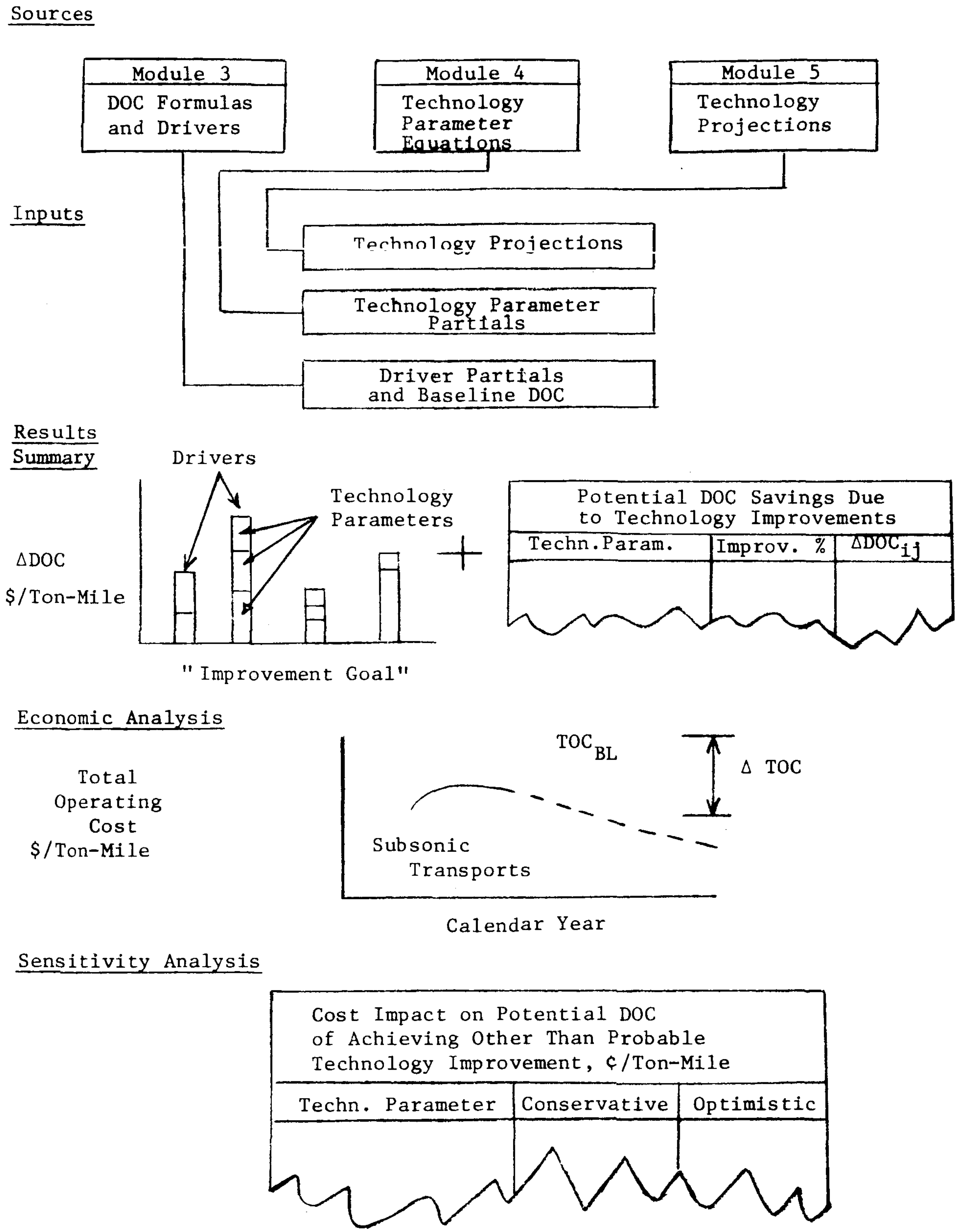

Figure 6-1.- Method Logic

calculated herein and represents a set of achievable "goals" for the constituent technologies. The ordinate represents the potential economic gain realized by achieving the goals. This data format, together with a tabulation of the individual Technology Parameter goals and gains, is the principal product of the subject methodology.

This module also includes an economic (total operating cost) comparison of the BGT, as improved by the Technology Projections, with conventional (subsonic) transport costs as forecast to the end of the century. The purpose of the comparison is to indicate, to the technology planner, the potential value of pursuing the technology goals. Appendix 6-A provides the background data and rationale on which the indirect operating cost portion of this step in the procedure is based.

Sensitivity analyses have been made (refer to Module 3) which demonstrate that the Driver partials and Technology Parameter partials are relatively insensitive to uncertainties in the baseline constants, costs, and operational parameters (e.g., engine maintenance ratios, depreciation life, reserve fuel fraction, etc.). These uncertainties will, however, impact the value of $(DOC)_{BL}$, but as inspection of the above equation shows, the uncertainties will have an equivalent (percentage) effect on ΔDOC_i. Therefore, since the relative magnitudes of ΔDOC_{ij} are unaffected by the above-mentioned uncertainties, they should have little significance to the previously drawn conclusions. From Module No. 5 the Technology Projections range from conservative to optimistic values. The impact upon the potential DOC of a failure to achieve the nominal improvement (as represented by the 50% confidence level value), or of a break-through to the optimistic value, is presented in a Sensitivity Table as illustrated in figure 6-1.

Input Data

The following data will be provided as inputs to this Method Module:

1. Technology Projections (Table 6-I).- The proportional improvement in each Technology Parameter (i) and the associated basis for the estimate, (percent confidence in achievement) from Method Module 5, Table 5-II.

2. Direct Operating Cost (Table 6-II).- DOC_{BL} and DOC_{TPS} for the baseline BGT from Method Module 3, Table 3-VI. (DOC_{TPS} is that component of DOC_{BL} chargeable to the thermal protection system.)

TABLE 6-I.- TECHNOLOGY PROJECTIONS - REQUIRED INPUT FOR MODULE 6

Technology Parameter, TP_i		$\Delta TP_i/TP_i$ Percent 10% (Optimistic)	50% (Probable)	90% (Conservative)
Aerodynamics				
C_{D_o}	zero-lift drag coefficient			
C_{D_i}/C_L^2	induced drag factor			
Airframe design				
$F_{W,B}$	design factor for wing structure designed by buckling criteria (= 1.00 for baseline)			
$F_{W,C}$	design factor for wing structure designed by crippling criteria (= 1.00 for baseline)			
$F_{W,S}$	design factor for wing structure designed by stiffness criteria (= 1.00 for baseline)			
$F_{W,Y}$	design factor for wing structure designed by yield criteria (= 1.00 for baseline)			
$F_{W,F}$	design factor for wing structure not designed by primary loads (= 1.00 for baseline)			
$F_{F,B}$	design factor for fuselage structure designed by buckling criteria (= 1.00 for baseline)			
$F_{F,C}$	design factor for fuselage structure designed by crippling criteria (= 1.00 for baseline)			

TABLE 6-I.- TECHNOLOGY PROJECTIONS - REQUIRED INPUT FOR MODULE 6 - Concluded

Technology Parameter, TP_i		$\Delta TP_i/TP_i$ Percent 10% (Optimistic)	50% (Probable)	90% (Conservative)
$F_{F,S}$	design factor for fuselage structure designed by stiffness criteria (= 1.00 for baseline)			
$F_{F,Y}$	design factor for fuselage structure designed by yield criteria (= 1.00 for baseline)			
$F_{F,F}$	design factor for fuselage structure not designed by primary loads (= 1.00 for baseline)			
F_E	design factor for empennage weight (= 1.00 for baseline)			
F_{PS}	design factor for propellant system weight (= 1.00 for baseline)			
Aggregate materials properties				
FMP	fuselage material properties			
WMP	wing material properties			
Thermal protection system				
$\left(\frac{W}{A}\right)_{TPS}$	average weight per unit area of thermal protection system			
L_{TPS}	TPS life in flights			
Propulsion				
I_{SP}	main engine vacuum specific impulse			
$\left(\frac{W}{T}\right)_{ME}$	main engine weight to sea-level thrust			

TABLE 6-II.- BASELINE DOC AND DRIVER PARTIALS - REQUIRED FOR MODULE 6

Baseline DOC, ¢/ton-mile		Driver Partials For the Driver Parameters:					
DOC_{BL}	DOC_{TPS}	$W_{AF}/GLOW$	$(W/A)_{TPS}$	$(W/T)_{ME}$	L/D	I_{SP}	L_{TPS}

3. Driver Partials (Table 6-II).- The ratio of the proportional improvement in DOC_{BL} to the proportional improvement in each Driver Parameter, (ΔDOC/DOC)/(ΔDriver/Driver); for each of the six Driver Parameters (j) from Method Module 3, Table 3-VI.

4. Technology Parameter Partials (Table 6-III).- The ratio of the proportional improvement in the applicable Driver Parameters to proportional improvements in each Technology Parameter, $\left(\frac{\Delta \text{Driver/Driver}}{\Delta \text{TP/TP}}\right)_{ij}$ from Method Module 4, Table 4-IV.

Procedures

1. The first step in the procedure is to calculate the proportional improvement in the baseline DOC which would result from each of the Technology Projections. This is accomplished by solving the following equation, using the 50% (probable) Technology Projections :

$$\left(\frac{\Delta \text{DOC}}{\text{DOC}}\right)_{ij} = \overbrace{\left(\frac{\Delta \text{DOC/DOC}}{\Delta \text{Driver/Driver}}\right)_{j}}^{\text{Driver Partial}} \times \overbrace{\left(\frac{\Delta \text{Driver/Driver}}{\Delta \text{TP/TP}}\right)_{ij}}^{\substack{\text{Technology}\\ \text{Parameter}\\ \text{Partial}}} \times \overbrace{\left(\frac{\Delta \text{TP}}{\text{TP}}\right)_{i}}^{\substack{\text{Technology}\\ \text{Projection}}}$$

(There will be only one solution to the equation for each Technology Parameter because each Technology Parameter influences only one Driver.)

(It may be noted that the product of the Driver partials and the Technology Parameter partials gives the sensitivity of proportional changes in DOC to proportional changes in each Technology Parameter, (ΔDOC/DOC)/(ΔTP/TP). This term may be of interest in some planning exercises).

2. Calculate the total incremental improvement (savings) in DOC_{BL} baseline which would result from each of the Technology Projections if implemented individually by the following equation:

$$\Delta \text{DOC}_{ij} = \left(\frac{\Delta \text{DOC}}{\text{DOC}}\right)_{ij} \times \text{DOC}_{BL}$$

TABLE 6-III.- TECHNOLOGY PARAMETER "PARTIALS" - REQUIRED INPUT FOR MODULE 6

Technology Parameter, TP_i		Applicable Driver	Value
<u>Aerodynamics</u>			
C_{D_o}	zero-lift drag coefficient	L/D	
$C_{D_i}/C_L{}^2$	induced drag factor	L/D	
<u>Airframe design</u>			
$F_{W,B}$	design factor for wing structure designed by buckling criteria (= 1.00 for baseline)	W_{AF}/GLOW	
$F_{W,C}$	design factor for wing structure designed by crippling criteria (= 1.00 for baseline)	W_{AF}/GLOW	
$F_{W,S}$	design factor for wing structure designed by stiffness criteria (= 1.00 for baseline)	W_{AF}/GLOW	
$F_{W,Y}$	design factor for wing structure designed by yield criteria (= 1.00 for baseline)	W_{AF}/GLOW	
$F_{W,F}$	design factor for wing structure not designed by primary loads (= 1.00 for baseline)	W_{AF}/GLOW	
$F_{F,B}$	design factor for fuselage structure designed by buckling criteria (= 1.00 for baseline)	W_{AF}/GLOW	
$F_{F,C}$	design factor for fuselage structure designed by crippling criteria (= 1.00 for baseline)	W_{AF}/GLOW	

TABLE 6-III.- TECHNOLOGY PARAMETER "PARTIALS" - REQUIRED INPUT FOR MODULE 6 - Concluded

Technology Parameter, TP_i		Applicable Driver	Value
$F_{F,S}$	design factor for fuselage structure designed by stiffness criteria (= 1.00 for baseline)	W_{AF}/GLOW	
$F_{F,Y}$	design factor for fuselage structure designed by yield criteria (= 1.00 for baseline)	W_{AF}/GLOW	
$F_{F,F}$	design factor for fuselage structure not designed by primary loads (= 1.00 for baseline)	W_{AF}/GLOW	
F_E	design factor for empennage weight (= 1.00 for baseline)	W_{AF}/GLOW	
F_{PS}	design factor for propellant system weight (= 1.00 for baseline)	W_{AF}/GLOW	
<u>Aggregate materials properties</u>			
FMP	fuselage material properties	W_{AF}/GLOW	
WMP	wing material properties	W_{AF}/GLOW	

3. Tabulate the ΔDOC_{ij} in a table as follows:

Potential DOC Savings Due to Technology Improvements, Individually		
Technology Parameters	% Improvement, (Probable)	ΔDOC_{ij}

4. Calculate the potential reduction in DOC_{BL} which would result from the probable improvement in all the Technology Parameters taken together. This is accomplished by use of the following expression:

$$\Delta DOC_{Pot} = \left\{ 1 - \Pi_i \left[1 - \left| \frac{\Delta DOC}{DOC} \right|_{ij} \right] \right\} \times DOC_{BL}$$

where Π_i means the product of the i terms. The following three steps are to determine the values to be presented in the results summary chart shown in figure 6-1.

5. Calculate the contribution to DOC_{Pot} made by each Technology Parameter from the following:

$$\Delta DOC'_{ij} = \frac{\Delta DOC_{Pot}}{\Sigma \Delta DOC_{ij}} \times \Delta DOC_{ij}$$

where $\Sigma \Delta DOC_{ij}$ is the arithmetic addition of all (20) ΔDOC_{ij}.

6. Sum the $\Delta DOC'_{ij}$ for the Technology Parameters which affect each Driver Parameter (j) giving ΔDOC_j.

$$\Delta DOC_j = \Sigma \Delta DOC'_{ij} \text{ for each Driver } (j = 1, 2, 3, 4, 5, 6)$$

This is the improvement in DOC_{BL} which would result from the improvement in the jth Driver.

7. Calculate the proportional improvement in each Driver by the following relationship:

$$\left(\frac{\Delta \text{Driver}}{\text{Driver}}\right)_j = \frac{\Delta DOC_j}{DOC_{BL}} \bigg/ \left(\frac{\Delta DOC/DOC}{\Delta Dr/Dr}\right)_j$$

(The term $\left(\frac{\Delta DOC/DOC}{\Delta \text{Driver}/\text{Driver}}\right)_j$ is the Driver partial which is input to this Method Module from Module 3.)

8. Plot the $\Delta DOC'_{ij}$, the ΔDOC_j and the $(\Delta \text{Driver}/\text{Driver})_j$ from steps 5, 6, and 7 above as illustrated in figure 6-2.

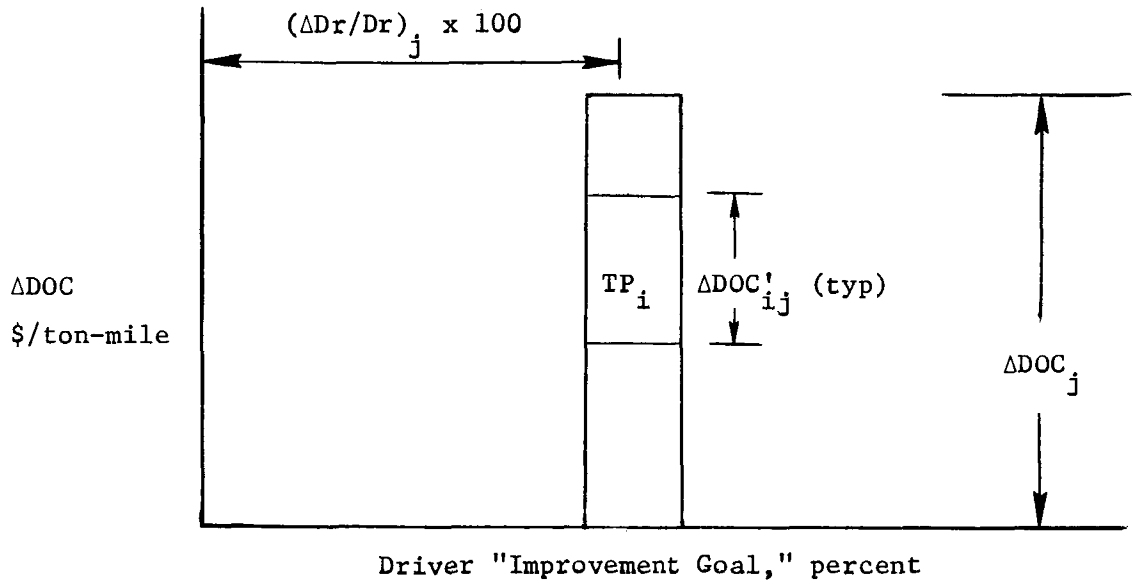

Figure 6-2.- Convention for Plotting Summary Results

9. Steps 9 through 12 provide for calculating the potential operating costs if all the technology improvements were achieved at the 50% (probable) level. A comparison is then made of this cost with projected airline industry operating costs (reference figure 6-3). Calculate the potential DOC as follows:

$$DOC_{Pot} = DOC_{BL} - \Delta DOC_{Pot}$$

10. The cost of propellant, C_P, is a significant factor in the economics of a BGT. As shown in figure 6-4, the cost of LH_2 was taken as 8¢/lbf (reference Module 3, Appendix C) at the end of the century. In performing the economic comparison, a different propellant cost increment/decrement can be accounted for in the following way:

$$\Delta DOC_{f'} = \left(\frac{DOC_f}{DOC_{BL}}\right)\left(1 - \frac{C'_P}{C_P}\right) DOC_{Pot}$$

where,

C'_P = revised propellant cost projection

C_P = propellant cost used in the baseline DOC

$\frac{DOC_f}{DOC_{BL}}$ = fraction of DOC_{BL} represented by propellant, from Module 3.

11. Estimate total operating cost (TOC) by adding indirect operating cost (IOC) to DOC. IOC consists of general, administrative, and service expenses which are generally independent of the flight system technology improvements. IOC can, therefore, be added as a fixed value to both DOC_{BL} and DOC_{Pot}. IOC has been estimated at \$.10 per ton-mile (invariant with time) for the BGT (reference Appendix 6-A), and TOC is computed as follows:

$$TOC_{BL} = DOC_{BL} + 0.10, \quad (\$/\text{ton-mile})$$

$$TOC_{Pot} = DOC_{Pot} + 0.10, \quad (\$/\text{ton-mile})$$

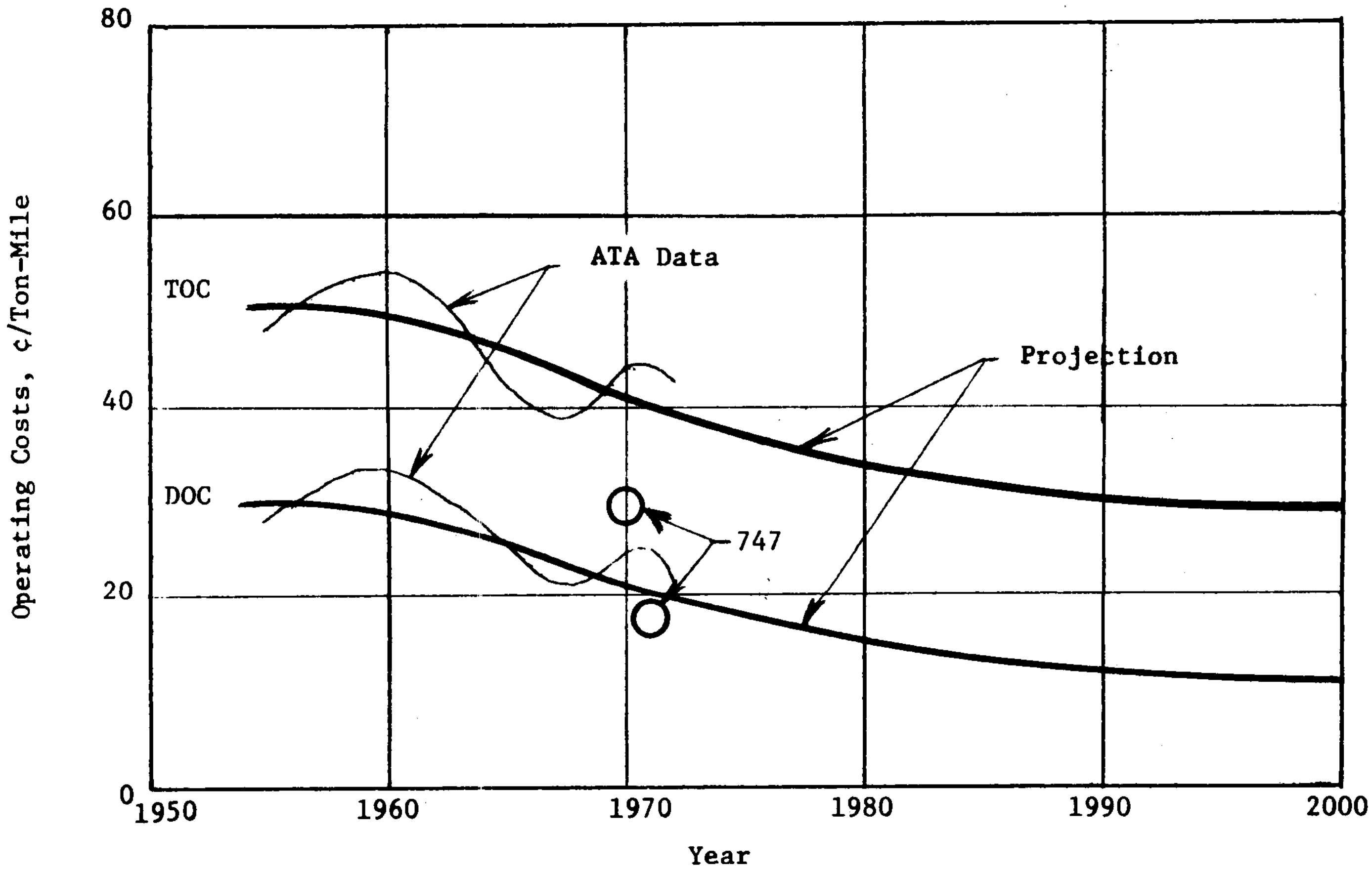

Figure 6-3.- Projected Average Airline Industry Operating Costs

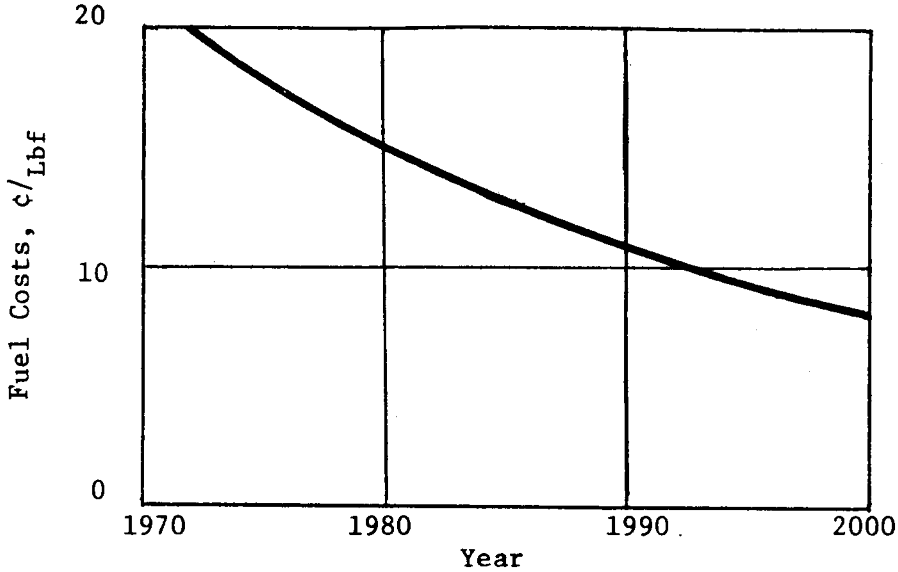

Figure 6-4.- Projected Cost of Liquid Hydrogen Fuel

12. Plot the TOC_{BL} and TOC_{Pot} on the projection of airline operating costs, Figure 6-3.

13. Sensitivity analysis.- The subsequent steps indicate the impact on the potential TOC and DOC of achieving other than the nominal (50% probable) value for the improvement in each technology area.

    When the 10% (optimistic) and 90% (conservative) confidence values for the Technology Projections have not been provided as data inputs to this module, estimate these values as follows:

    90% (conservative) value = 0.6 x 50% (probable) value

    10% (optimistic) value = 1.4 x 50% (probable) value

14. Calculate the incremental improvement in DOC_{BL} which would results from achieving the 10% (optimistic) and 90% (conservative) levels of improvement in the Technology Parameters, ΔDOC_{ij}, by repeating steps 1, 2, 4, and 5 above using the 10% (optimistic) and 90% (conservative) values.

15. Calculate the impact on the potential DOC of achieving other than the 50% (probable) level of technology by subtracting ΔDOC_{ij} calculated in step 5 from the two sets of values obtained in step 14 above. Tabulate these in the following format:

COST IMPACT ON POTENTIAL DOC OF ACHIEVING OTHER THAN THE PROBABLE TECHNOLOGY PROJECTIONS, $/TON-MILE

Technology Parameter	Conservative Projection	Optimistic Projection

DEMONSTRATION

This section provides an illustration of how the procedures of this Method Module are to be applied.

Input Data

The input data for the demonstration are based on the data from the Demonstration sections of the other modules of this report.

1. The Technology Projections are given in Table 6-IV and are outputs from Module 5, Technology Projections, Table 5-V.

2. The baseline DOC's for the baseline BGT are shown in Table 6-V, taken from the output of Module 3, Table 3-IV.

3. The "Driver partials" (ΔDOC/DOC)/(ΔDriver/Driver) are also presented in Table 6-V and are outputs from Module 3, Table 3-IX.

4. The "Technology Parameter partials" are presented in Table 6-VI and are outputs from Module 4, Technology Parameter Equations, Table 4-VII.

Procedures

Steps 1 and 2.- The procedures of steps 1 and 2, which give the estimated reduction in the baseline DOC which would result from the Technology Projections, are illustrated in Table 6-VII, Tabulation Work Sheet.

The projected improvements in the Technology Parameters to the 50% probable level have been entered in column 4. The reduction in DOC for the projected improvement in each Technology Parameter is shown in column 6.

(The term (ΔDOC/DOC)/(ΔTP/TP), which is the sensitivity of proportional improvements in DOC to proportional improvements in each Technology Parameter, is the product of column (2) and column (3) and can be computed separately, if desired.)

Step 3. - The tabulation of ΔDOC_{ij} for the improvement in each Technology Parameter has been tabulated in Table 6-VIII. The results indicate, for example, that the 10% improvement projected in C_{D_o} taken individually would yield a 19.7¢ per ton-mile reduction in DOC.

TABLE 6-IV.- TECHNOLOGY PROJECTIONS - DEMONSTRATION DATA INPUT FOR MODULE 6 (Reference TABLE 6-I)

Technology Parameter, TP_i		$\Delta TP_i/TP_i$ Percent 10% (Optimistic)	50% (Probable)	90% (Conservative)
Aerodynamics				
C_{D_o}	zero-lift drag coefficient	-20	-10	0
C_{D_i}/C_L^2	induced drag factor	-5	-2.5	0
Airframe design				
$F_{W,B}$	design factor for wing structure designed by buckling criteria (= 1.00 for baseline)		10	
$F_{W,C}$	design factor for wing structure designed by crippling criteria (= 1.00 for baseline)		10	
$F_{W,S}$	design factor for wing structure designed by stiffness criteria (= 1.00 for baseline)		10	
$F_{W,Y}$	design factor for wing structure designed by yield criteria (= 1.00 for baseline)		10	
$F_{W,F}$	design factor for wing structure not designed by primary loads (= 1.00 for baseline)		10	
$F_{F,B}$	design factor for fuselage structure designed by buckling criteria (= 1.00 for baseline)		10	
$F_{F,C}$	design factor for fuselage structure designed by crippling criteria (= 1.00 for baseline)		10	

TABLE 6-IV.- TECHNOLOGY PROJECTIONS - DEMONSTRATION DATA INPUT FOR MODULE 6 (Reference TABLE 6-I) - Concluded

Technology Parameter, TP_i		$\Delta TP_i/TP_i$ Percent 10% (Opti-mistic)	50% (Prob-able)	90% (Conser-vative)
$F_{F,S}$	design factor for fuselage structure designed by stiffness criteria (= 1.00 for baseline)		10	
$F_{F,Y}$	design factor for fuselage structure designed by yield criteria (= 1.00 for baseline)		10	
$F_{F,F}$	design factor for fuselage structure not designed by primary loads (= 1.00 for baseline)		10	
F_E	design factor for empennage weight (= 1.00 for baseline)		10	
F_{PS}	design factor for propellant system weight (= 1.00 for baseline)		10	
<u>Aggregate materials properties</u>				
FMP	fuselage material properties		-10	
WMP	wing material properties		-10	
<u>Thermal protection system</u>				
$\left(\frac{W}{A}\right)_{TPS}$	average weight per unit area of thermal protection system		-10	
L_{TPS}	TPS life in flights	+1328*	+1328*	+614
<u>Propulsion</u>				
I_{SP}	main engine vacuum specific impulse	+2	0	0
$\left(\frac{W}{T}\right)_{ME}$	main engine weight to sea-level thrust		10	

*Projection assumes TPS can last for the life of the transport.

TABLE 6-V.- BASELINE DOC AND DRIVER PARTIALS - DEMONSTRATION DATA INPUT FOR MODULE 6 (Reference TABLE 6-II)

Baseline DOC, ¢/ton-mile		Driver Partials For the Driver Parameters:					
DOC_{BL}	DOC_{TPS}	$W_{AF}/GLOW$	$(W/A)_{TPS}$	$\left(W_{ME}/T\right)$	L/D	I_{SP}	L_{TPS}*
183.8	80.6	4.37	1.11	1.38	-3.17	-18.25	-0.014

*Driver Partial for L_{TPS} evaluated at the projected value of 7140 flights.

TABLE 6-VI.- TECHNOLOGY PARAMETER "PARTIALS" - DEMONSTRATION DATA INPUT FOR MODULE 6 (Reference TABLE 6-III)

Technology Parameter, TP_i		Applicable Driver	Value
Aerodynamics			
C_{D_o}	zero-lift drag coefficient	L/D	-0.338
C_{D_i}/C_L^2	induced drag factor	L/D	-0.661
Airframe design			
$F_{W,B}$	design factor for wing structure designed by buckling criteria (= 1.00 for baseline)	$(W_{AF}/GLOW)$	-0.013
$F_{W,C}$	design factor for wing structure designed by crippling criteria (= 1.00 for baseline)	$(W_{AF}/GLOW)$	-0.007
$F_{W,S}$	design factor for wing structure designed by stiffness criteria (= 1.00 for baseline)	$(W_{AF}/GLOW)$	-0.007
$F_{W,Y}$	design factor for wing structure designed by yield criteria (= 1.00 for baseline)	$(W_{AF}/GLOW)$	-0.040
$F_{W,F}$	design factor for wing structure not designed by primary loads (= 1.00 for baseline)	$(W_{AF}/GLOW)$	-0.044
$F_{F,B}$	design factor for fuselage structure designed by buckling criteria (= 1.00 for baseline)	$(W_{AF}/GLOW)$	-0.056
$F_{F,C}$	design factor for fuselage structure designed by crippling criteria (= 1.00 for baseline)	$(W_{AF}/GLOW)$	-0.011

TABLE 6-VI.- TECHNOLOGY PARAMETER "PARTIALS" - DEMONSTRATION DATA INPUT FOR MODULE 6 (Reference TABLE 6-III) - Concluded

Technology Parameter, TP_i		Applicable Driver	Value
$F_{F,S}$	design factor for fuselage structure designed by stiffness criteria (= 1.00 for baseline)	$(W_{AF}/GLOW)$	-0.006
$F_{F,Y}$	design factor for fuselage structure designed by yield criteria (= 1.00 for baseline)	$(W_{AF}/GLOW)$	-0.034
$F_{F,F}$	design factor for fuselage structure not designed by primary loads (= 1.00 for baseline)	$(W_{AF}/GLOW)$	-0.226
F_E	design factor for empennage weight (= 1.00 for baseline)	$(W_{AF}/GLOW)$	-0.032
F_{PS}	design factor for propellant system weight (= 1.00 for baseline)	$(W_{AF}/GLOW)$	-0.327
Aggregate materials properties			
FMP	fuselage material properties	$(W_{AF}/GLOW)$	0.337
WMP	wing material properties	$(W_{AF}/GLOW)$	0.111

TABLE 6-VII.- TABULATION WORK SHEET FOR PROCEDURES STEPS 1-7

Technology Parameter	Applicable Driver	"Driver Partial"	"TP Partial"	Technology Projection, 50% (Probable)	$\left(\frac{\Delta DOC}{DOC}\right)_{ij}$
Column No.	1	2	3	4	5 = 2 x 3 x 4
Procedures Step No. →	←			1	→
C_{D_o}	L/D	-3.17	-0.338	-0.10	-0.107
$C_{D_i}/C_L{}^2$	L/D	-3.17	-0.661	-0.025	-0.052
$F_{W,B}$	W_{AF}/GLOW	4.37	-0.013	0.10	-0.006
$F_{W,C}$	"	4.37	-0.007	0.10	-0.003
$F_{W,S}$	"	4.37	-0.007	0.10	-0.003
$F_{W,Y}$	"	4.37	-0.040	0.10	-0.017
$F_{W,F}$	"	4.37	-0.044	0.10	-0.019
$F_{F,B}$	"	4.37	-0.056	0.10	-0.024
$F_{F,C}$	"	4.37	-0.011	0.10	-0.005
$F_{F,S}$	"	4.37	-0.006	0.10	-0.003
$F_{F,Y}$	"	4.37	-0.034	0.10	-0.015
$F_{F,F}$	"	4.37	-0.226	0.10	-0.099
F_E	"	4.37	-0.032	0.10	-0.014
F_{PS}	"	4.37	-0.327	0.10	-0.143
WMP	"	4.37	0.111	-0.10	-0.049
FMP	"	4.37	0.337	-0.10	-0.147
$(W/A)_{TPS}$	$(W/A)_{TPS}$	1.11	1.0	-0.10	-0.111
L_{TPS}	L_{TPS}	-0.014	1.0	+13.28	-0.186
I_{SP}	I_{SP}	-18.25	1.0	0	0
$(W/T)_{ME}$	$(W/T)_{ME}$	1.38	1.0	-0.10	-0.138

TABLE 6-VII.- TABULATION WORK SHEET FOR PROCEDURES STEPS 1-7 - Concluded

Technology Parameter	ΔDOC_{ij} 50% (Probable) \$/ton-mile	$\left(1-\left\|\frac{\Delta DOC}{DOC}\right\|\right)_{ij}$	$\Delta DOC'_{ij}$	ΔDOC_j \$/ton-mile	$\left(\frac{\Delta Driver}{Driver}\right)_j$
Column No.	6 = 5 x DOC_{BL}	7	8	9	10 = (9 / DOC_{BL}) / 2
Procedures Step No. →	2	4	5	6	7
C_{D_o}	-0.197	0.893	-0.121		
C_{D_i}/C_L^2	-0.096	0.948	-0.059	-0.180	0.031
$F_{W,B}$	-0.011	0.994	-0.007		
$F_{W,C}$	-0.006	0.997	-0.004		
$F_{W,S}$	-0.006	0.997	-0.004		
$F_{W,Y}$	-0.031	0.983	-0.019		
$F_{W,F}$	-0.035	0.981	-0.021		
$F_{F,B}$	-0.044	0.976	-0.027		
$F_{F,C}$	-0.009	0.995	-0.006		
$F_{F,S}$	-0.006	0.997	-0.004		
$F_{F,Y}$	-0.028	0.985	-0.017		
$F_{F,F}$	-0.182	0.901	-0.112		
F_E	-0.026	0.986	-0.016		
F_{PS}	-0.263	0.857	-0.162		
WMP	-0.090	0.951	-0.055		
FMP	-0.270	0.853	-0.166	-0.620	0.077
$(W/A)_{TPS}$	-0.204	0.889	-0.126	-0.126	0.062
L_{TPS}	-0.342	0.814	-0.212	-0.212	8.236
I_{SP}	0	1.000	0	0	0
$(W/T)_{ME}$	-0.254	0.862	-0.156	-0.156	0.061

$$\prod_i \left(1-\left|\frac{\Delta DOC}{DOC}\right|_{ij}\right) = 0.296$$

TABLE 6-VIII.- REDUCTION IN DOC_{BL} FROM ACHIEVEMENT OF THE PROBABLE IMPROVEMENT IN EACH TECHNOLOGY PARAMETER, INDIVIDUALLY

Technology Parameter, TP_i		% improvement in Technology Parameter	ΔDOC_{ij} ¢/ton-mile
Aerodynamics			
C_{D_o}	zero-lift drag coefficient	-10	-19.7
C_{D_i}/C_L^2	induced drag factor	-2.5	-9.6
Propulsion			
I_{SP}	main engine vacuum specific impulse	0	0
$\left(\frac{W}{T}\right)_{ME}$	main engine weight to sea-level thrust ratio	-10	-25.4
Airframe design			
$F_{W,B}$	design factor for wing structure designed by buckling criteria (= 1.00 for baseline)	10	-1.1
$F_{W,C}$	design factor for wing structure designed by crippling criteria (= 1.00 for baseline)	10	-0.6
$F_{W,S}$	design factor for wing structure designed by stiffness criteria (= 1.00 for baseline)	10	-0.6
$F_{W,Y}$	design factor for wing structure designed by yield criteria (= 1.00 for baseline)	10	-3.1
$F_{W,F}$	design factor for wing structure not designed by primary loads (= 1.00 for baseline)	10	-3.5

TABLE 6-VIII.- REDUCTION IN DOC_{BL} FROM ACHIEVEMENT OF THE PROBABLE IMPROVEMENT IN EACH TECHNOLOGY PARAMETER, INDIVIDUALLY - Concluded

Technology Parameter, TP_i		% improvement in Technology Parameter	ΔDOC_{ij} ¢/ton-mile
$F_{F,B}$	design factor for fuselage structure designed by buckling criteria (= 1.00 for baseline)	10	-4.4
$F_{F,C}$	design factor for fuselage structure designed by crippling criteria (= 1.00 for baseline)	10	-0.9
$F_{F,S}$	design factor for fuselage structure designed by stiffness criteria (= 1.00 for baseline)	10	-0.6
$F_{F,Y}$	design factor for fuselage structure designed by yield criteria (= 1.00 for baseline)	10	-2.8
$F_{F,F}$	design factor for fuselage structure not designed by primary loads (= 1.00 for baseline)	10	-18.2
F_E	design factor for empennage weight (= 1.00 for baseline)	10	-2.6
F_{PS}	design factor for propellant system weight (= 1.00 for baseline)	10	-26.3
Aggregate materials properties			
FMP	fuselage material properties	-10	-27.0
WMP	wing material properties	-10	-9.0
Thermal protection system			
$(W/A)_{TPS}$	average weight per unit area of thermal protection	-10	-20.4
L_{TPS}	TPS life in number of flights	+1328	-34.2

Step 4.- The potential reduction in DOC_{BL} which would result from the projected 50% (probable) improvements in all the Technology Parameters combined is calculated as $1.404¢ per ton-mile by the relationship:

$$\Delta DOC_{Pot} = \left\{ 1 - \prod_i \left[1 - \left| \frac{\Delta DOC}{DOC} \right|_{ij} \right] \right\} \times DOC_{BL}$$

$$= \left\{ 1 - .296 \right\} \times 1.838$$

$$= \$1.294/\text{ton-mile}$$

The values of $1 - \left| \frac{\Delta DOC}{DOC} \right|_{ij}$ and their products are taken from column 7 of Table 6-VII.

Step 5.- The approximate proportional contribution of the improvement in each Technology Parameter to ΔDOC_{Pot} is calculated in column 8 of Table 6-VII.

$$\Delta DOC'_{ij} = \frac{\Delta DOC_{Pot}}{\Sigma \Delta DOC_{ij}} \times DOC_{ij}$$

$$= \frac{\$1.294}{2.100} \times DOC_{ij}$$

The contribution of the improvement in the Technology Parameter, C_{D_o}, to the overall reduction, if all improvements were achieved, is approximately 11.6¢ per ton-mile. The Technology Parameters are not independent so that this contribution is less than if the reduction in C_{D_o} were achieved individually.

Steps 6 and 7.- The proportional improvement in each Driver and the contribution of each Driver to the combined reduction in DOC is calculated in columns 9 and 10 of Table 6-VII.

Step 8.- The results of steps 6 and 7 are plotted in figure 6-5.

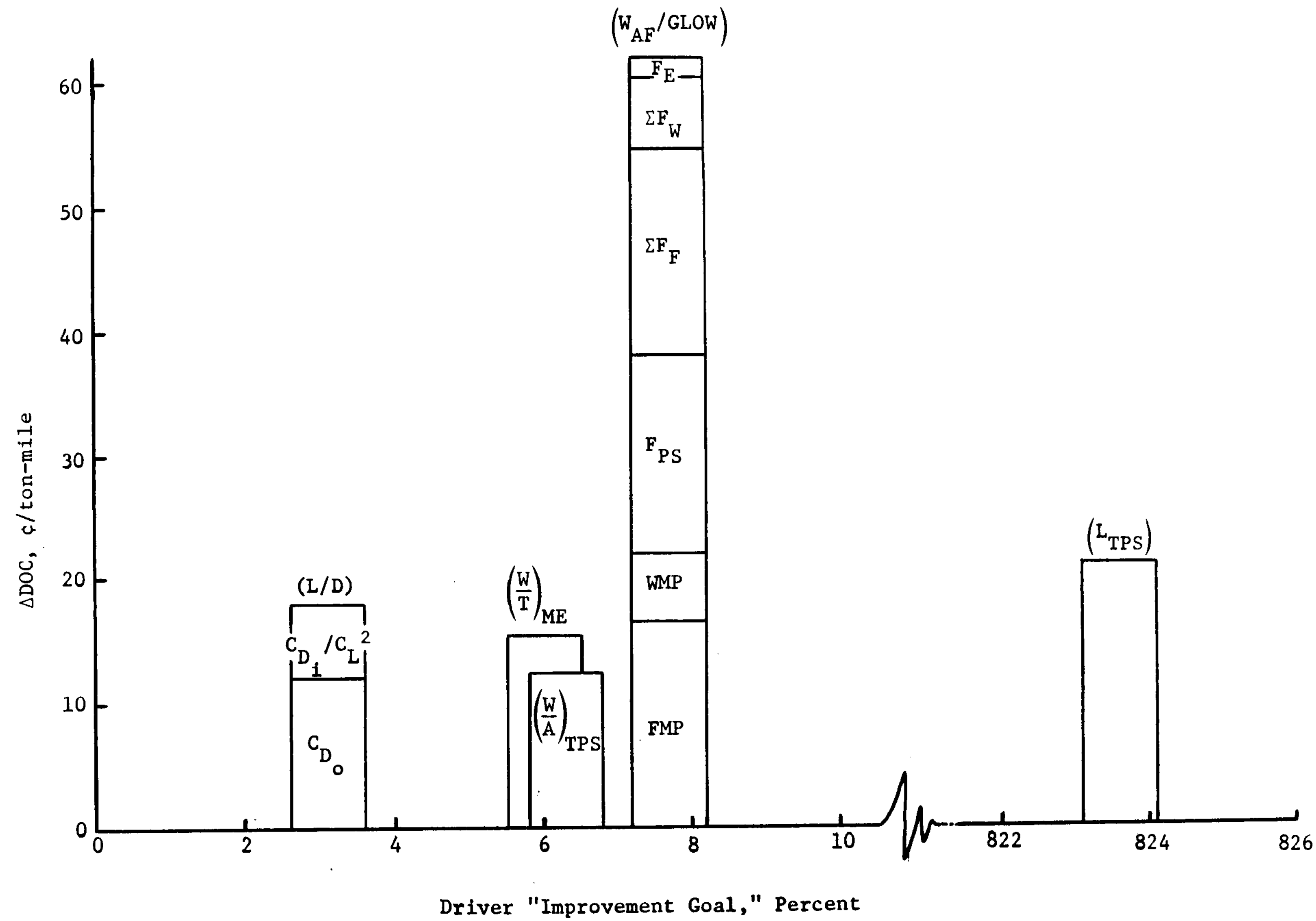

Figure 6-5.- Results Summary Chart

Step 9.- The potential DOC value which would result from achievement of the 50% (probable) level of improvement in all the Technology Parameters combined is calculated as 43.4¢ per ton-mile as follows:

$$DOC_{Pot} = DOC_{BL} - \Delta DOC_{Pot}$$

$$DOC_{Pot} = 183.9 - 129.4 = 54.5 \text{ ¢/ton-mile}$$

Step 10.- A hydrogen cost of 8¢/lb and an oxygen cost of 1.2¢/lb was used for the demonstration.

Step 11.- The values for TOC_{BL} and $TOC_{Potential}$ are calculated by adding IOC = 10¢ per ton-mile to the DOC values.

$$TOC_{BL} = DOC_{BL} + 10 = 193.9\text{¢ per ton-mile}$$

$$TOC_{Potential} = DOC_{Pot} + 10 = 54.5 + 10 = 64.5\text{¢ per ton-mile}$$

In other words, the baseline TOC for the BGT is estimated at 193.8¢ per ton-mile. This could potentially be reduced to 64.5¢ per ton-mile by the combined effect of the improvements 50% (probable) in all the Technology Parameters and by the projected reduction in fuel cost to the end of the century.

Step 12.- The TOC values from step 11 are compared with the projected industry operating costs in figure 6-6. The results indicate a potential BGT total operating cost of 64.4¢ per ton-mile based on the achievement of all the technology improvements as projected at the 50% (probable) level would be within 35.5¢ per ton-mile of the projected industry average of 29¢ per ton-mile at a target date of about 2000.

Steps 13-15, Sensitivity analysis.- The results of the sensitivity analysis, steps 13-15, are presented in Table 6-IX. The 90% (conservative) and 10% (optimistic) projections in the Technology Projections were estimated by the procedures of step 13 for this demonstration.

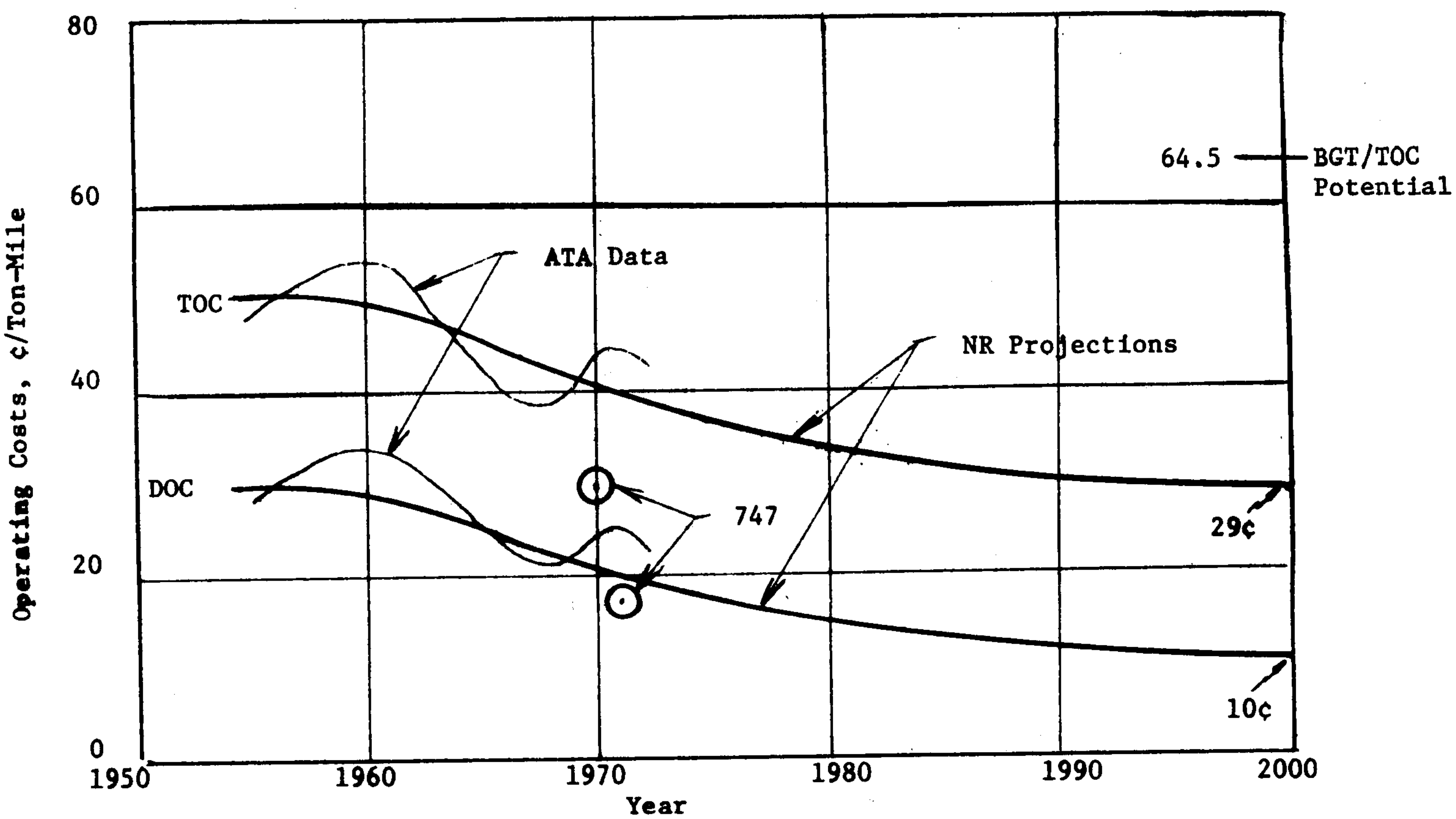

Figure 6-6.- Comparison of BGT Operating Costs with Projected Airline Industry Operations Costs (50% Probable Technology Improvements)

TABLE 6-IX.- COST IMPACT ON POTENTIAL DOC OF ACHIEVING OTHER THAN THE NOMINAL TECHNOLOGY IMPROVEMENTS, ¢/TON-MILE

	Technology Parameter, TP_i	ΔDOC in ¢/ton-mile from 50% confidence projection: Conservative Projection	Optimistic Projection
Aerodynamics			
C_{D_o}	zero-lift drag coefficient	12.1	-5.5
C_{D_i}/C_L^2	induced drag factor	5.9	-2.7
Propulsion			
I_{SP}	specific impulse	0	-30.0
$(W/T)_{ME}$	main engine weight-to-thrust	3.3	-0.3
Airframe design			
$F_{W,B}$	design factor for wing structure designed by buckling criteria (= 1.00 for baseline)	0.2	0
$F_{W,C}$	design factor for wing structure designed by crippling criteria (= 1.00 for baseline)	0.1	0
$F_{W,S}$	design factor for wing structure designed by stiffness criteria (= 1.00 for baseline)	0.1	0
$F_{W,Y}$	design factor for wing structure designed by yield criteria (= 1.00 for baseline)	0.4	0
$F_{W,F}$	design factor for wing structure not designed by primary loads (= 1.00 for baseline)	0.4	-0.1
$F_{F,B}$	design factor for fuselage structure designed by buckling criteria (= 1.00 for baseline)	0.6	-0.1

TABLE 6-IX.- COST IMPACT ON POTENTIAL DOC OF ACHIEVING OTHER THAN THE NOMINAL TECHNOLOGY IMPROVEMENTS, ¢/TON-MILE - Concluded

Technology Parameter, TP_i		ΔDOC in ¢/ton-mile from 50% confidence projection: Conservative Projection	Optimistic Projection
$F_{F,C}$	design factor for fuselage structure designed by crippling criteria (= 1.00 for baseline)	0.2	0
$F_{F,S}$	design factor for fuselage structure designed by stiffness criteria (= 1.00 for baseline)	0.1	0
$F_{F,Y}$	design factor for fuselage structure designed by yield criteria (= 1.00 for baseline)	0.3	0
$F_{F,F}$	design factor for fuselage structure not designed by primary loads (= 1.00 for baseline)	2.4	-0.2
F_E	design factor for empennage weight (= 1.00 for baseline)	0.3	0
F_{PS}	design factor for propellant system weight (= 1.00 for baseline)	3.5	-0.3
Aggregate materials properties			
FMP	fuselage material properties	3.5	-0.3
WMP	wing material properties	1.2	-0.1
Thermal protection system			
$(W/A)_{TPS}$	average unit weight of TPS	2.8	-0.1
L_{TPS}	TPS life in number of flights	8.5	5.9

REFERENCES

1. Anon: Air Transport Facts and Figures, Official Publication of the Air Transport Association of America, 1966.

2. Anon: Air Transport 1972, The Annual Report of the U.S. Scheduled Airline Industry, Published by the Air Transport Association of America, 1972.

3. Anon: Aviation Week and Space Technology, 747 Operating Cost Data, prepared by Ray and Ray, July 31, 1972, October 2, 1972, and December 18, 1972.

4. Lewis, H., The Role of Air Freight in Physical Distribution, Pergamon Press, 1956.

APPENDIX 6-A

INDIRECT OPERATING EXPENSE (IOC) FOR BGT

Indirect operating expenses include general and administrative expenses, all costs related to ground equipment and facilities, passenger costs, and aircraft servicing including terminal fees, ramp personnel, and turnaround costs.

IOC was projected to the target year, 2000, at 21¢ per ton-mile in the HST study (reference 6-A-1) based on an examination of U.S. airline experience for the past ten years. These data show that IOC has remained between 22.3¢ and 17.4¢ in that time. It was 22.3¢ in 1961 and 21.3¢ in 1971 (reference 6-A-2).

Three considerations are indicated for application of the same projection to the BGT:

1. An increased allowance should be made for additional ground support equipment and facilities including transporter-erector vehicles.

2. An increased allowance should be made in aircraft or vehicle servicing costs which include the vertical launch pad operations plus fees for the terminal facilities.

3. The IOC is much more nearly related to number of flights than to ton-miles flown. Therefore, the costs should be computed on a per flight basis before application to the BGT and then reconverted to the ton-mile basis. Otherwise, the very long distance flights, of the order of 18 000 km (11 000 miles) for the BGT would weight these costs too heavily.

A breakdown of the projected 21¢ per ton-miles into subaccounts from the ATA data is presented in Table 6-A-1. The breakdown is based on experience for international airlines which it was felt more closely reflect BGT operation than the domestic lines. The international lines had an actual IOC of approximately 18.5¢ per ton-mile in 1971. These lines carried an average of 11.2 tons payload and flew an average of 1671 miles per flight (departure) (18 760 ton-miles per flight). The projected 21¢ per ton-mile then amounts to $3940 per flight. It is judged that the aircraft servicing costs and ground property and equipment costs should be

TABLE 6-A-1.- IOC PROJECTION SUMMARY

IOC Subaccounts	Projected Cost for Airplanes		Adjusted for BGT
	¢ per ton-mile	$ per flight	$ per flight
Aircraft Servicing	3.7	691	6910
Traffic Servicing	3.7	689	689
Servicing Administration	0.5	107	107
Passenger Service	4.5	837	837
Promotion and Sales	5.6	1051	1051
Ground Property and Equipment (Maintenance and Depreciation)	1.1	199	1990
General and Administrative	1.9	366	366
	21.0	3940	11 950

increased an order of magnitude for the BGT which results in an IOC of $11,950 per flight.

The ton-miles per flight for the baseline BGT are calculated as $W_{PL} \times LF \times R_T = 119\ 460$,

$$IOC = \frac{\$11,950}{119\ 460} = 10¢ \text{ per ton-mile}$$

References

6-A-1 Repic, E. M., et al.: "A Methodology for Hypersonic Transport Technology Planning," NASA CR 2286, June 1973.

6-A-2 Anon: Air Transport 1972, The Annual Report of the U.S. Scheduled Airline Industry, Published by the Air Transport Association of America, 1972.

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